# General Standard TMDL (Total Maximum Daily Load) Development for Black Creek Wise County, Virginia

Prepared By

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### *Introduction*

Black Creek is located in Wise County, Virginia, just west of the Town of Norton. It was placed on the Commonwealth of Virginia's 1998 303(d) List of Impaired Waters because of violations of the general standard (benthic). The impaired stream segment has a length of 5.94 miles, and extends from the Black Creek Lake impoundment to the confluence with the Powell River near Rt. 58/23. The land area of the Black Creek Watershed is approximately 2,300 acres, with forest and mining as the primary land uses. Approximate proportions of specific land uses are 24.7% forest, 56.9% disturbed lands (areas disturbed by previous mining operations through removal of vegetation and/or grading), 16.3% spoils (mine waste discarded in fills or piles), 1.7% benches (abandoned surface mine sites leaving exposed high walls), and 0.4% water.

### *General Standard (Benthic) Impairment*

An assessment of the benthic macro invertebrate community was conducted by Donald Cherry, PhD. of Virginia Tech. The results of this study led to Black Creek being placed on the Commonwealth of Virginia's 1998 303(d) List of Impaired Waters for not supporting the state's aquatic life use. The applicable state standard (Virginia State Law 9VAC25-260-20) specifies that all state waters shall be free of substances, which are inimical or harmful to aquatic life. The Rapid Bioassessment Protocol II (RBP) was used to assess compliance with state law.

The General Standard does not identify the stressor(s) -e.g. pollutant(s)- that are harmful to aquatic life. A significant portion of this study was dedicated to identifying the stressors and their relationship to aquatic life as measured by the RBP. A multiparameter statistical analysis was conducted to determine the primary stressors and their mathematical relationship. This analysis identified eleven stressors (i.e. pH, acidity, alkalinity, dissolved solids, total suspended solids, dissolved and total iron, dissolved and total manganese, sulfate, and specific conductivity) potentially impacting the health of the aquatic community. The mathematical relationships allowed for the allocations to be applied to the stressors while maintaining the aquatic life measures as the endpoint.

### *Sources of the Impairment*

Potential sources contributing to the impairment include both nonpoint source contributions and point sources. Nonpoint sources include acid mine drainage (AMD) and abandoned mine lands (AML), which include, mine spoils, benches, and disturbed areas. At the time of Cherry's study there were two permitted point discharges in the Black Creek drainage area. Both were from sedimentation basins, used to control losses from surface mining disturbances. Subsequent to Cherry's work seven additional discharges have been permitted. All but one of which are outlets from ponds associated with current surface mining activities. The final permitted discharge was drainage from a deep mine.

### *Water Quality Modeling*

The US Geological Survey (USGS) Hydrologic Simulation Program - Fortran (HSPF) water quality model was selected as the modeling framework to simulate hydrologic and water quality conditions. Seasonal variations in hydrology, climatic conditions, and watershed activities were explicitly accounted for in the model.

Discrete flow measurements made as a requirement of mining permits were used to calibrate hydrologic flows for the Black Creek watershed in the HSPF model, thereby improving confidence in computed discharges generated by the model. The representative hydrologic period used for calibration ran from October 1991 through September 1995. The time period covered by calibration represented the hydrologic regime of the study area, accounting for critical conditions associated with all potential sources within the watershed. For purposes of modeling watershed inputs to in-stream water quality, the Black Creek drainage area was divided into fifteen subwatersheds. The model was calibrated for water quality predictions using data collected October 1991 through May 1995. All allocation model runs were conducted using precipitation data from October 1991 through September 1995.

### *Biometric Modeling*

Linked to the HSPF water quality model was the seven biometric models and the RBP calculator producing a continuous modeled bioassessment. As with the hydrologic and water quality modeling, seasonal variations were explicitly accounted for in the model. The biometric models were validated using data collected during the Cherry study, and data collected in October 2001, by Environmental Services & Consulting, LLC, in support of this study.

### *Existing Loadings and Water Quality Conditions*

Both point and nonpoint sources were represented in the model. The only permitted point sources during the modeled period were discharges from control structures. These point sources were each modeled with appropriate characteristics to model the sediment trapping capacity of the structure. Nonpoint sources were modeled as having four potential delivery pathways, delivery with sediment in surface runoff, delivery through interflow, delivery through groundwater, and delivery through direct discharge of mine seeps to the stream. Delivery through direct discharge by mine seeps was modeled by adding a time series of pollutant and flow inputs to the stream. Much of the data used to develop the model inputs for modeling water quality is time-dependent (e.g. existence of control structures). The hydrologic landscape of the watershed was relatively stable during the modeled period (1991-1995). Data representing this period were used to develop the model used in this study.

### *Margin of Safety*

In order to account for uncertainty in modeled output, a margin of safety (MOS) was incorporated into the TMDL development process. A margin of safety can be incorporated implicitly in the model through the use of conservative estimates of model parameters, or explicitly as an additional load reduction requirement. Individual errors in model inputs, such as data used for developing model parameters or data used for calibration, may affect the load allocations in a positive or a negative way. The purpose of the MOS is to avoid an overall bias toward load allocations that are too large for meeting the water quality target. An implicit MOS was used in the development of this TMDL.

### Load Allocation Scenarios

The next step in the TMDL process was to adjust loadings to account for permitted discharges that would impact allocation scenarios, and determine how to proceed from existing watershed conditions to reduce the various source loads to levels that would result in attainment of the water quality standards. Scenarios were evaluated to predict the effects of different combinations of source reductions on final in-stream water quality. Modeling of these scenarios provided predictions of whether the reductions would achieve the target of an average bioassessment score for the modeled period of 85% or greater. Allocations were developed for three stations on Black Creek; the outlet of subwatershed 5 in upper Black Creek, the outlet of subwatershed 11 in lower Black Creek, and the outlet of subwatershed 21 representing the outlet of the entire watershed. Inputs from upstream subwatersheds were based on allocated loads for those areas. The final load allocation scenario varied by allocated station, and required:

- 0-93% reduction in manganese loads from nonpoint sources (including AMD)
- 0-66% reduction conductivity loads from nonpoint sources (including AMD)
- 0-79% increase in alkalinity loads from nonpoint sources (including AMD), and
- 80% reduction in the manganese load from the direct mine discharge permitted under mine permit #1201542.

The 80% reduction in the manganese load from the direct mine discharge was determined relative to current permitted loads.

### Recommendations for TMDL Implementation

The goal of this TMDL was to develop an allocation plan that will lead to the attainment of water quality standards. Virginia's 1997 Water Quality Monitoring, Information and Restoration Act states in Section 62.1-44.19.7 that the "Board shall develop and implement a plan to achieve fully supporting status for impaired waters". Since this TMDL consists primarily of NPS load allocations originating from mining activities, VADMME will have the lead responsibility for the development of the implementation plan. VADMME and VADEQ will work closely with watershed stakeholders, interested state agencies, and support groups to develop an acceptable implementation plan that will result in meeting the water quality target.

The TMDL developed for the Black Creek impairment provides allocation scenarios that will be a starting point for developing implementation strategies. A staged implementation plan is essential to the process of restoring water quality. The first stage was initiated with the installation of two constructed wetlands located on the main stem of Black Creek. Installation of the wetlands was completed in 2001. VADMME is currently evaluating the efficacy of these practices in improving water quality within Black Creek.

It is anticipated that the AML and AMDs will be initial targets of implementation. One way to accelerate reclamation of AML is through remining. The Virginia Department of Mines, Minerals and Energy's Division of Mined Land Reclamation, The Nature Conservancy, Virginia Tech/Powell River Project, and U. S. Office of Surface Mining combined resources to develop proposals for incentives that will promote economically viable, environmentally beneficial remining operations that reclaim AML sites. The first stage of the implementation represents preliminary steps in achieving the final allocation. A staged implementation plan is necessarily an iterative process. There is a measure of uncertainty associated with the final allocation development process. Continued monitoring can provide insight into the effectiveness of implementation strategies, the need for amending the plan, and/or progress toward the eventual removal of the impairment from the 303(d) list.

### *Public Participation*

During development of the TMDL for the Black Creek Watershed, public involvement was encouraged through public and focal group meetings. In developing the TMDL, three public meetings were held, involving citizens from all areas of the Black Creek Watershed. An introduction of the agencies involved, an overview of the TMDL process and the specific approach to developing the Black Creek TMDL were presented at the first of the two public meetings. The first meeting included members of the mining industry, regulatory agency and MapTech personnel. Details of the hydrologic calibration, pollutant sources, water quality modeling and initial results from the biometrics model simulations were presented during the second public meeting. During the third and final meeting results of the water quality model, biometrics models and load allocations were presented. Public understanding of and involvement in the TMDL process was encouraged. Input from these meetings was utilized in the development of the TMDL and improved confidence in the allocation scenarios developed.

# ACKNOWLEDGMENTS

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Red River Coal

Coastal Coal

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# 1. INTRODUCTION

## 1.1 Background

EPA's document, *Guidance for Water Quality-Based Decisions: The TMDL Process* (USEPA, 1999) states:

> *According to Section 303(d) of the Clean Water Act and EPA water quality planning and management regulations, States are required to identify waters that do not meet or are not expected to meet water quality standards even after technology-based or other required controls are in place. The waterbodies are considered water quality-limited and require TMDLs .*
>
> *. . . A TMDL, or total maximum daily load, is a tool for implementing State water quality standards and is based on the relationship between pollution sources and in-stream water quality conditions. The TMDL establishes the allowable loadings or other quantifiable parameters for a waterbody and thereby provides the basis for States to establish water quality-based controls. These controls should provide the pollution reduction necessary for a waterbody to meet water quality standards.*

According to the *1998 303(d) Total Maximum Daily Load Priority List and Report* (VADEQ, 1998), Black Creek and its tributaries are listed as impaired. Black Creek carries an agency watershed ID of VAS-P17R. Virginia Department of Environmental Quality (VADEQ) has identified Black Creek as being impaired with regard to the general standard (benthic), based on the results of a study (Cherry et al., 1997) conducted by Donald Cherry, Professor of Biology, Virginia Tech, which was funded by the Virginia Department of Mine Land Reclamation (VADMLR).

The Black Creek watershed is located in Wise County, Virginia, just west of the Town of Norton (Figure 1.1). The impaired stream segment has a length of 5.94 miles, and extends from the Black Creek Lake impoundment to the confluence with the Powell River near Rt. 58/23 (Figure 1.2). Black Creek flows into the Powell River, which is part of the Upper Tennessee River Drainage Basin, and drains via the Mississippi River to the Gulf of Mexico. The land area of the Black Creek Watershed is approximately 2,300 acres, with forest and mining as the primary land uses (Figure 1.3). Approximate proportions of specific land uses are 24.7% forest, 56.9% disturbed lands (areas disturbed by previous mining operations through removal of vegetation and/or grading), 16.3% spoils (mine waste discarded in fills or piles), 1.7% benches (abandoned surface mine sites leaving exposed high walls), and 0.4% water.

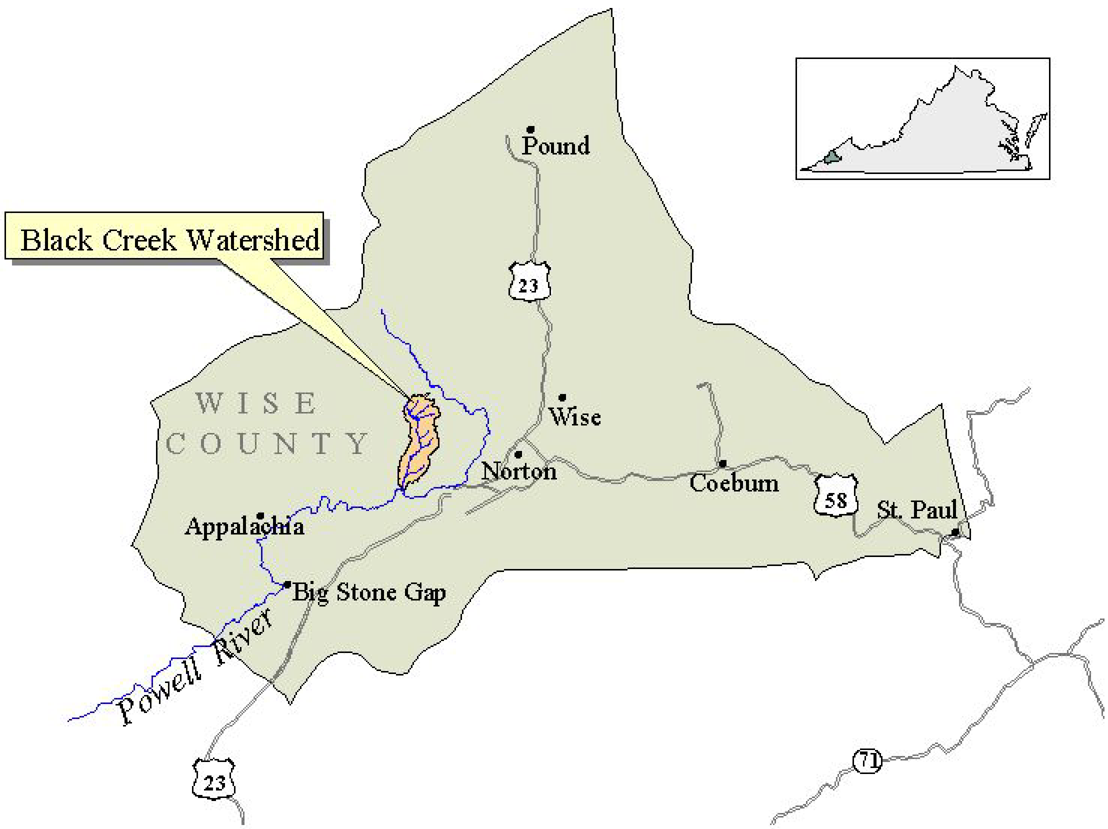


**Figure 1.1 Location of the Black Creek Watershed.**

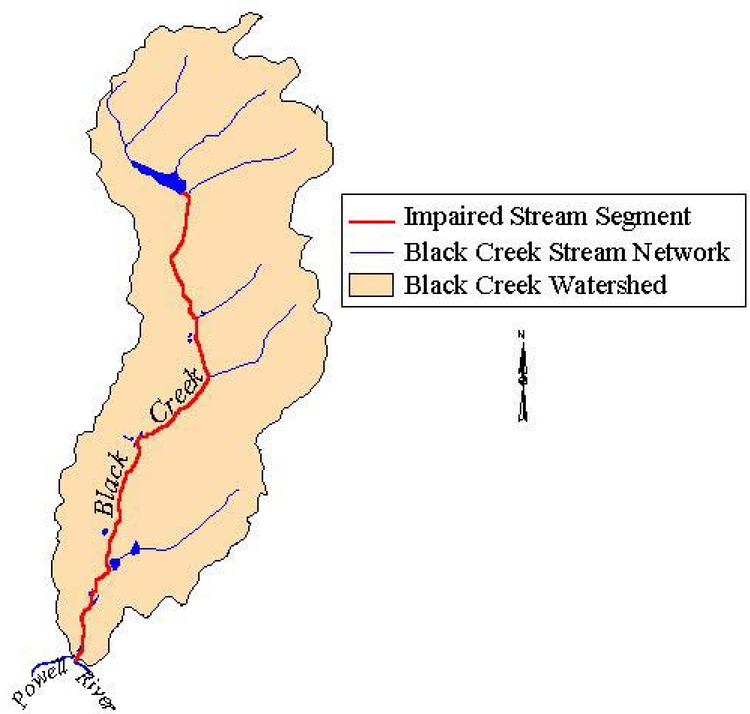


**Figure 1.2 Impaired Stream Segment of the Black Creek Watershed.**

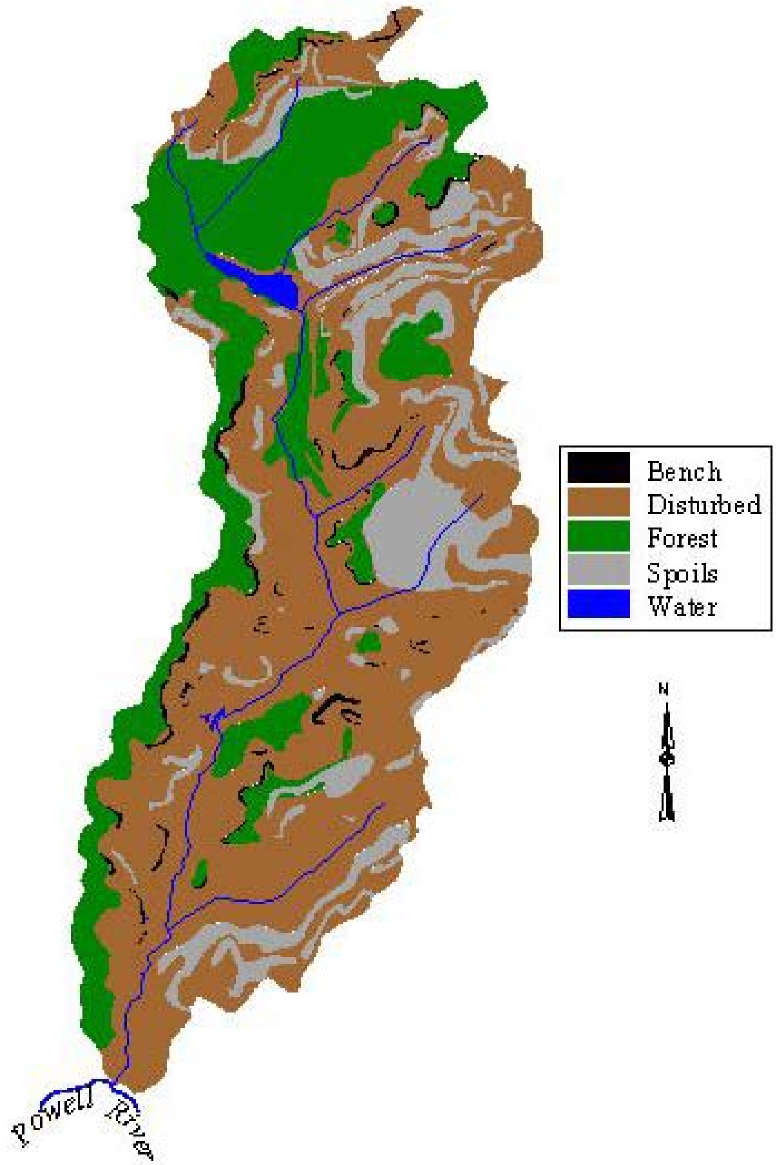


**Figure 1.3 Land uses in the Black Creek Watershed, 1996.**

### *1.2 Applicable Water Quality Standards*

Virginia state law 9VAC25-260-10 (Designation of uses) indicates:

A. *All state waters, including wetlands, are designated for the following uses: recreational uses, e.g., swimming and boating; the propagation and growth of a balanced, indigenous population of aquatic life, including game fish, which might reasonably be expected to inhabit them; wildlife; and the production of edible and marketable natural resources, e.g., fish and shellfish.*

♦

D. *At a minimum, uses are deemed attainable if they can be achieved by the imposition of effluent limits required under §§301(b) and 306 of the Clean Water Act and cost-effective and reasonable best management practices for nonpoint source control.*

♦

*G. The [State Water Control] board may remove a designated use which is not an existing use, or establish subcategories of a use, if the board can demonstrate that attaining the designated use is not feasible because:*

*1. Naturally occurring pollutant concentrations prevent the attainment of the use;*

*2. Natural, ephemeral, intermittent or low flow conditions or water levels prevent the attainment of the use unless these conditions may be compensated for by the discharge of sufficient volume of effluent discharges without violating state water conservation requirements to enable uses to be met;*

♦

*6. Controls more stringent than those required by §§301(b) and 306 of the Clean Water Act would result in substantial and widespread economic and social impact.*

Additionally, Virginia state law 9VAC25-260-20 defines the **General Standard** as:

*A. All state waters, including wetlands, shall be free from substances attributable to sewage, industrial waste, or other waste in concentrations, amounts, or combinations which contravene established standards or interfere directly or indirectly with designated uses of such water or which are inimical or harmful to human, animal, plant, or aquatic life.*

### 1.3 Implementation of the General Standard

The General Standard is implemented by VADEQ through application of the Rapid Bioassessment Protocol II (RBP). Using the RBP, the health of the benthic macroinvertebrate community is typically assessed through measurement of 8 biometrics (Table 1.1), which measure different aspects of the communities overall health. The Black Creek study is a slight exception, using only 7 of the 8 biometrics. Surveys of the benthic macroinvertebrate community performed by VADEQ are assessed at the family taxonomic level. It is this bioassessment that is the endpoint for general standard impaired TMDLs.

Each biometric measured at a target station is compared to the same biometric measured at a reference (non-impaired) station to determine each biometric score. These scores are then summed and used to determine the overall bioassessment (e.g. non-impaired, moderately impaired, or severely impaired).

**Table 1.1 Components of the RBP Assessment**

| Biometric | Benthic Health [1] |
|---|---|
| Taxa Richness | ↑ |
| Modified Family Biotic Index | ↓ |
| Scraper to Filtering Collector Ratio | ↑ |
| EPT / Chironomid Ratio | ↑ |
| % Contribution of Dominant Family | ↓ |
| EPT Index | ↑ |
| Community Loss Index | ↓ |
| Shredder to Total Ratio | ↑ |

[1] An upward arrow indicates a positive response in benthic health when the associated biometric increases.

## *1.4 Project Design*

There were two distinct elements of the Black Creek TMDL project. The first was development of a model that reflects the standard, considers seasonality and critical conditions, and allows for assessing pollutant allocation scenarios. The second element was implementation of the model to determine an allocation scenario for Black Creek.

In developing a TMDL for a narrative standard, it is necessary to establish measurable endpoints for the analysis. In the case of Virginia's General Standard, a relationship between the health of the impaired aquatic community (i.e. benthic macroinvertebrates) and the stressor(s) causing the impairment (e.g. pH) must be defined either implicitly or explicitly. Developing this link or relationship was a key component of this project and is discussed in greater detail in Section 2.1 and Appendix A. In order to accomplish this task, biological, chemical and physical data were compiled from the Black Creek drainage, as well as, from similar areas (Figure 1.4). Data were collected from studies conducted by Virginia Tech (Cherry, et al. 1997), VADEQ, VADMLR, and Appalachian Technology Services (ATS). Multi-parameter statistical analyses were performed on the compiled data set, to identify the primary stressor(s) causing the impairment and to establish a mathematical relationship between stressor levels and the specific biometrics used by VADEQ to measure the health of the benthic community. The result of this task was a set of equations (biometric models) that allows for the calculation of biometrics based on stressor levels that are either modeled or measured prior to use of the biometric models. By combining these biometric models with an existing pollutant loading and delivery model(s), allocation scenarios were assessed with regard to meeting the standard, while considering seasonality and critical conditions.

The US Geological Survey (USGS) Hydrologic Simulation Program - Fortran (HSPF) water quality model was selected as the modeling framework to simulate hydrologic conditions and stressor levels in Black Creek. These output data were then used as inputs to the biometric models. Consequently, time-series output for each of the modeled biometrics was produced at multiple locations in the watershed, including the reference station. A temporal distribution of biometric scores and corresponding bioassessments was then calculated based on the methodology currently used in Virginia. Allocation scenarios that outlined reductions in stressor loads were then run using HSPF and the biometric models to determine if a non-impaired status was attainable with the proposed scenario. In this way, an allocation scenario was developed that will promote recovery of the water body, with consideration for seasonal differences and an array of critical hydrologic conditions.

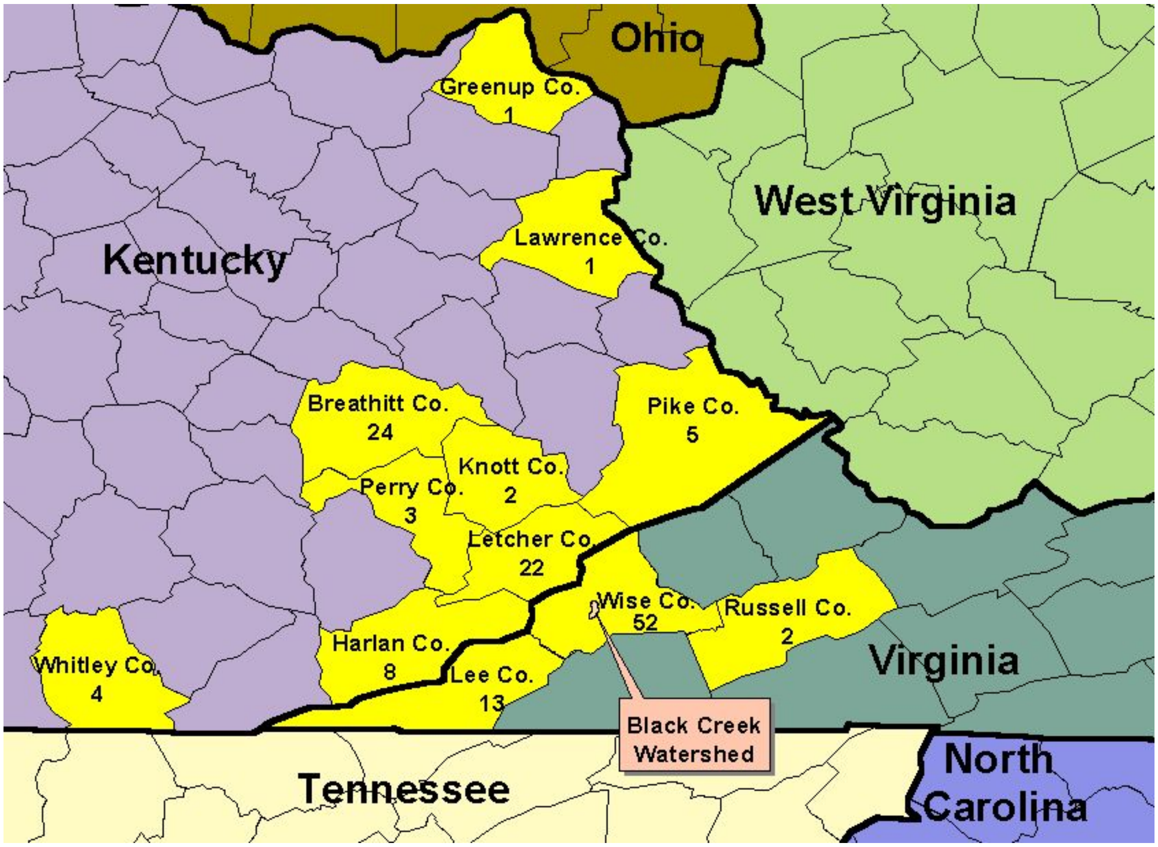


**Figure 1.4 Location of data sources used in developing the biometric models.**

# 2. TMDL ENDPOINT AND WATER QUALITY ASSESSMENT

Black Creek was initially placed on the Virginia 1996 303(d) list of impaired waters based on monitoring performed in August and October of 1995. Black Creek remained on the state's 303(d) list for the 1998 assessment. The monitoring for the assessment was performed by Professor Donald Cherry, Department of Biology, Virginia Tech, and measured the health of aquatic life through assessment of seven of the eight biometrics used by VADEQ in their bioassessments (Cherry et al., 1997). Surveys of the benthic macroinvertebrate community performed by Cherry indicated that this stream segment does not support aquatic life use.

## *2.1 Development of the TMDL Endpoint*

The first step in developing a TMDL is the establishment of measurable in-stream endpoints, which are used to evaluate the attainment of acceptable water quality. In-stream endpoints, therefore, represent the water quality goals that are to be achieved by implementing the load reductions specified in the TMDL. The endpoints for the Black Creek impairment were developed based on the criteria used to assess the general standard. Based on these criteria, the "non-impaired" status of the stream was defined as the endpoint for TMDL allocations. To be consistent with the original assessment of Black Creek that resulted in its 303(d) listing, the same reference station was used for assessing modeled allocations. This station is located on the main stem of Black Creek just upstream of Black Creek Lake (i.e. Cherry's UBC-1, Figure 2.5). Additionally, the same biometrics used by Cherry in the original assessment of Black Creek were used in this analysis (i.e. seven of the eight biometrics used by VADEQ, with "shredder to total ratio" being the excluded biometric, Table 1.1).

The quantification of the term "non-impaired" required the development of biometric models that link the RBP protocol to stream conditions. This was accomplished by identifying important stressors and developing biometric models that link stressor levels with the specific biometrics used by VADEQ to measure the health of the benthic community. A multi-parameter statistical analysis was conducted using the dataset discussed in Section 1.4 to determine the primary stressors and their mathematical relationship with the seven biometrics used by Professor Cherry in implementing the RBP on Black Creek. The primary stressors causing the impairment were identified as:

- pH
- Acidity
- Alkalinity
- Dissolved & Total Iron
- Dissolved & Total Manganese
- Sulfate
- Total Dissolved Solids
- Total Suspended Solids
- Specific Conductivity

Specific details on the procedure used to develop the biometric models are given on page 3, Appendix A. The biometric model for Taxa Richness is typical of the type relationships that were developed.

$$\boldsymbol{TR} = -19.48 - 0.082(TDS) - 0.065(Sulfates) - 1.75 \ln(DMn) - 3.11 \ln(DFe) + 2.99 \ln(TMn) + 3.36 \ln(TFe) + 9.19 \ln(TDS) - 10.75(DMn)^2 + 0.136(pH)^2 - 0.00018(Alk)^2 - 0.15(TFe)^2 - 10.09(TMn)^2 + 0.00012(TDS)^2$$

Where:

| | |
|---|---|
| TDS = total dissolved solids | Alk = alkalinity |
| DMn = dissolved manganese | TMn = total manganese |
| DFe = dissolved iron | TFe = total iron |

The complexity of this model and other biometric models developed for this study reflect the inherent complexity of biological systems. Non-linear responses to stressing agents are not uncommon in these systems. For example, aquatic communities are adversely affected by a low pH, as well as a high pH. In addition, these models reflect the cumulative impact of stressing agents on biological systems.

The Hydrologic Simulation Program FORTRAN (HSPF) was used to simulate a time-series of values for stressors at specified locations in Black Creek. The time-series output was used with the seven biometric models to calculate expected biometric values from which bioassessments were calculated and used to provide an estimate of the status of the water body, i.e. severely impaired, moderately impaired or non-impaired. The process is illustrated in Figures 2.1, 2.2, and detailed in Appendix A.

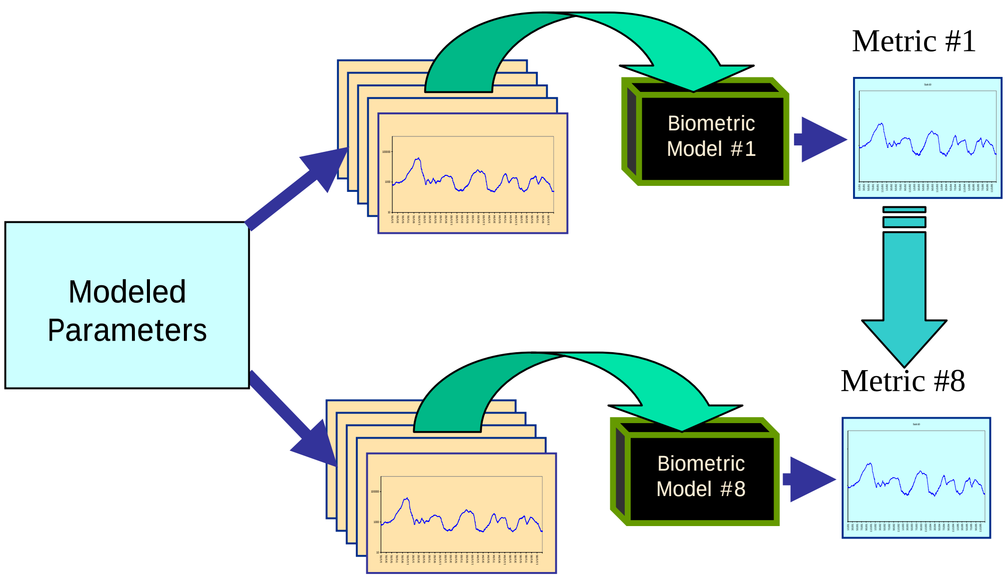


**Figure 2.1 Conceptual application of the linkage between the water quality and biometric models.**

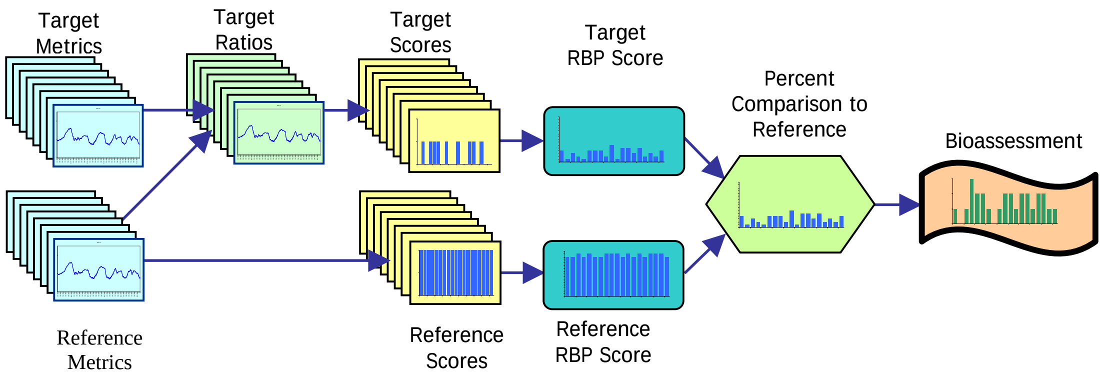


**Figure 2.2 Application of the bioassessment protocal.**

To further refine the quantification of the RPB endpoint for non-impaired status, an attempt was made to define inherent variability in the process by evaluating bioassessment for VADEQ reference stations located in Virginia coalfields. Although this analysis would not be expected to represent a comprehensive analysis of variability related to biological assessments, it was expected to provide some insight into the range of bioassessments that would be helpful to further refine a criterion for the non-impaired status for Black Creek. A total of 67 records were identified in the VADEQ database (Table B.1, Appendix B), representing 37 reference stations, with some stations monitored multiple times. The records were ordered from one to 67 and sequentially one record was chosen as the reference station to assess the remaining 66 records. The resulting bioassessments for 67 comparisons are displayed in Figure 2.3. The average bioassessment for these reference stations was 85%, a non-impaired status, with variability extending to severely impaired in a few instances. These results suggest that variability among reference station bioassessments is common. They also strongly suggest that basing the endpoint definition on an average bioassessment score of 85% would likely result in a stream status of non-impaired. The endpoint criterion established for allocations was an average daily simulated bioassessment score of 85%.

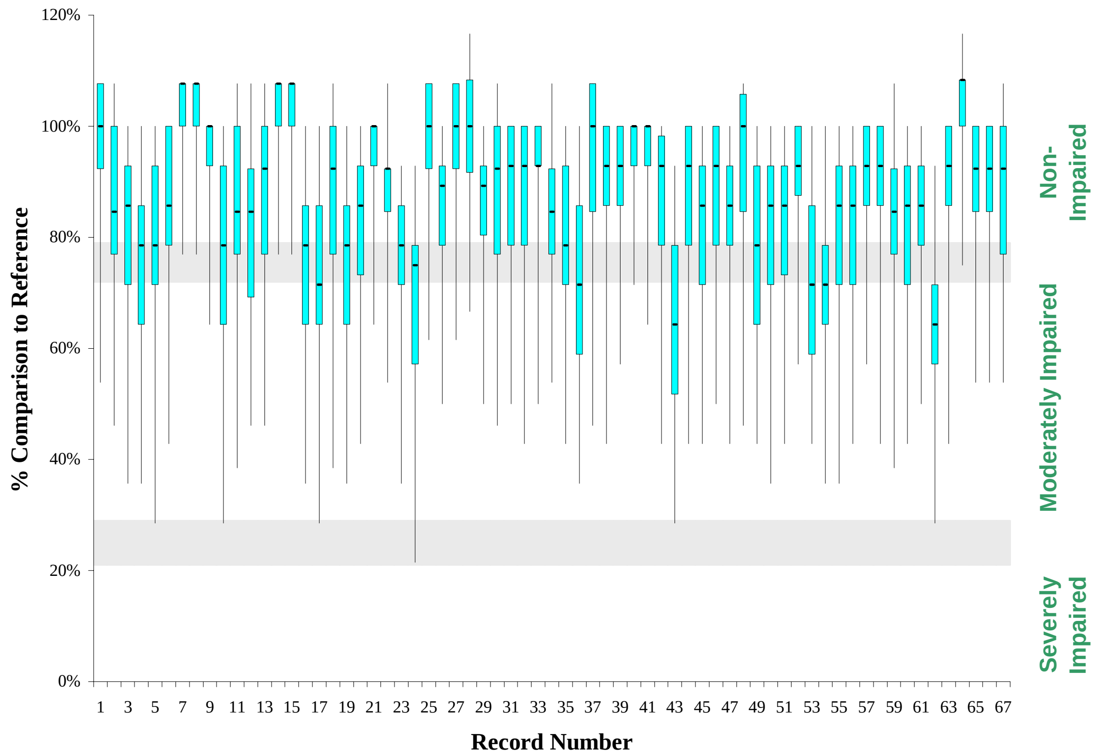


**Figure 2.3 Comparison of bioassessment variability in VADEQ established reference stations.**

## *2.2 Selection of a Critical Condition(s)*

By its nature, assessment of aquatic health through the RBP reveals the impacts of stressors throughout a variety of hydrologic conditions. As such, modeling performed to assess the effectiveness of allocation scenarios should represent a wide range of typical hydrologic conditions. The sparseness of data available and the need to accurately model the period leading up to the bioassessments performed in 1995, limited the selection of potential modeling periods. Additionally, data collected in the watershed after June 1, 1995 was called into question during the second public meeting. Due to the uncertain validity of these data, they were not used for calibration of the model. A time period for modeling was chosen based on the overall distribution of wet and dry seasons (Section 4.5). The resulting time period for modeling allocation scenarios was October 1991 through September 1995.

## *2.3 Discussion of In-stream Water Quality*

This section provides an inventory and analysis of available observed in-stream monitoring data throughout the Black Creek Watershed. Sources of data and pertinent results are discussed.

### 2.3.1 Inventory of Water Quality Monitoring Data

Black Creek has been monitored to support mine permit applications, mine permit compliance, academic studies, and assessment by VADMLR. The primary sources of available water quality information are:

- Data compiled from mine permit application/compliance monitoring by D.R. Allen & Associates for a pre-TMDL report
- Virginia Tech, Department of Biology study, conducted by Professor Cherry
- VADMLR monitoring to assess the impact of remediation measures

Where available, minimum detection levels are reported. Where zero values were reported in the original work, zero values were used to develop the data presented here.

#### *2.3.1.1 Mine Permit Application/Compliance Monitoring*

Several labeling schemes have been applied in the Black Creek Watershed to identify monitoring stations established in support of mine permit application and compliance procedures. In order to simplify discussion of water quality in the watershed, D.R. Allen, a consulting firm under contract with VADMLR, assigned labels based on the "milepoint" of the site. The milepoint indicates the distance, in miles, from Black Creek's confluence with the Powell River. A station identified as "2.10+0.04" would be located 0.04 miles up a tributary that enters Black Creek 2.10 miles upstream from the Powell River. Figure 2.4 shows the location of monitoring sites, for which data have been compiled.

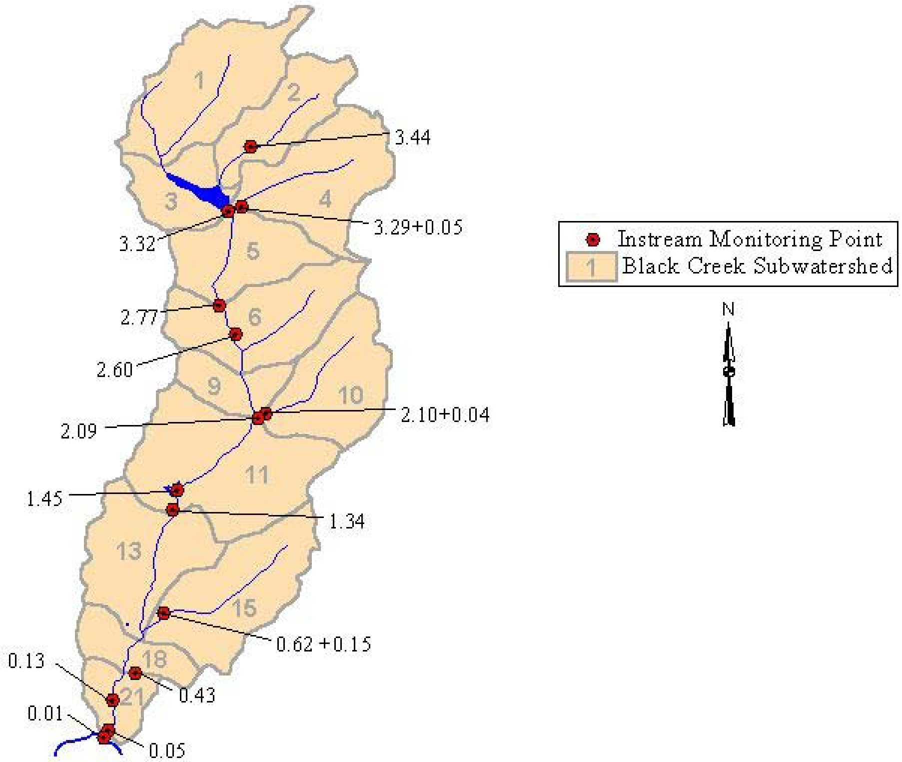


**Figure 2.4 Location of in-stream water quality monitoring stations associated with mine permitting processes in the Black Creek Watershed.**

Tables 2.1 through 2.11 show summaries of the water quality data collected at each of 11 in-stream monitoring locations in the Black Creek Watershed. Sampling was performed by various personnel representing both the coal mining industry and consultants hired by mining companies. Sample timing varied based on the mine permit that the sample was intended to support. Abbreviations used in these tables include: TDS (Total Dissolved Solids), Fe (Total Iron), Mn (Total Manganese), and TSS (Total Suspended Solids). All flow values that contributed to these summaries were estimated.

While it is difficult to draw many conclusions from these data due to differences in sample timing, it appears that there are some distinct differences between measurements taken at the lake outlet (Milepoint 3.32) and those taken at downstream locations where mining activities have had a larger impact. There also appears to be a difference in the delivery of water quality constituents downstream. Some of the constituents typically associated with acid mine drainage (e.g. sulfate, conductivity, and total dissolved solids) are consistently higher at locations downstream of the lake outlet, while others (e.g. acidity, total iron, and total manganese) spike at certain points in the stream and return to levels that are closer to those seen at the lake outlet. This suggests that the first group of constituents tends to be conservative once in the stream, while constituents in the second group tend to "decay" upon entering the stream. This observation is supported by the existence of mine seeps just upstream of these "spike" locations.

**Table 2.1 In-stream Water Quality Data for Milepoint 0.05 (Sampled 7/95-3/96)**

| Mile 0.05 | Mean | Median | Max | Min | SD[1] | N[2] |
|---|---|---|---|---|---|---|
| FLOW (gpm) | 813.89 | 1,000 | 2,000 | 75 | 628.13 | 9 |
| TEMP (ºC) | 12.00 | 12 | 20 | 2 | 6.38 | 9 |
| PH | 7.78 | 8 | 8 | 7 | 0.36 | 9 |
| ACIDITY (mg/L CaCO3) | 0 | 0 | 0 | 0 | 0 | 9 |
| ALKALINITY (mg/L $CaCO_3$) | 50.22 | 45 | 89 | 31 | 18.51 | 9 |
| CONDUCTIVITY (µmhos/cm) | 673.33 | 560 | 1,700 | 400 | 397.68 | 9 |
| TDS (mg/L) | 636.67 | 584 | 938 | 222 | 247.31 | 9 |
| FE (mg/L) | 0.23 | 0.16 | 0.77 | 0.02 | 0.26 | 9 |
| MN (mg/L) | 0.31 | 0.08 | 0.79 | 0.02 | 0.32 | 9 |
| SULFATE (mg/L) | 361.78 | 360 | 530 | 46 | 165.25 | 9 |
| TSS (mg/L) | 4.56 | 1 | 14 | 1 | 5.13 | 9 |

[1]SD: standard deviation, [2]N: number of sample measurements

**Table 2.2 In-stream Water Quality Data for Milepoint 0.13 (Sampled 11/96-3/99)**

| Mile 0.13 | Mean | Median | Max | Min | SD[1] | N[2] |
|---|---|---|---|---|---|---|
| FLOW (gpm) | 6,050.00 | 5,750 | 19,000 | 500 | 4,240.75 | 30 |
| TEMP (ºC) | 13.23 | 12.5 | 24 | 4 | 6.01 | 30 |
| PH | 7.47 | 7.5 | 8 | 6.8 | 0.33 | 30 |
| ACIDITY (mg/L $CaCO_3$) | 0 | 0 | 0 | 0 | 0 | 30 |
| ALKALINITY (mg/L $CaCO_3$) | 81.33 | 64.5 | 181 | 37 | 41.59 | 30 |
| CONDUCTIVITY (µmhos/cm) | 799.33 | 690 | 1,700 | 350 | 334.50 | 30 |
| TDS (mg/L) | 600.40 | 601 | 1,384 | 92 | 311.11 | 30 |
| FE (mg/L) | 0.75 | 0.15 | 11.5 | 0.1 | 2.09 | 30 |
| MN (mg/L) | 0.28 | 0.2 | 1 | 0.1 | 0.23 | 30 |
| SULFATE (mg/L) | 285.33 | 230 | 700 | 25 | 186.14 | 30 |
| TSS (mg/L) | 9.83 | 7 | 56 | 1 | 11.41 | 30 |

[1]SD: standard deviation, [2]N: number of sample measurements

**Table 2.3 In-stream Water Quality Data for Milepoint 0.43 (Sampled 1/96-3/96)**

| Mile 0.43 | Mean | Median | Max | Min | SD[1] | N[2] |
|---|---|---|---|---|---|---|
| FLOW (gpm) | 18.33 | 20 | 20 | 15 | 2.89 | 3 |
| TEMP (ºC) | 8.00 | 10 | 12 | 2 | 5.29 | 3 |
| PH | 6.83 | 6.5 | 7.5 | 6.5 | 0.58 | 3 |
| ACIDITY (mg/L $CaCO_3$) | 0 | 0 | 0 | 0 | 0 | 3 |
| ALKALINITY (mg/L $CaCO_3$) | 34.33 | 16 | 71 | 16 | 31.75 | 3 |
| CONDUCTIVITY (µmhos/cm) | 586.67 | 510 | 750 | 500 | 141.54 | 3 |
| TDS (mg/L) | 463.33 | 444 | 504 | 442 | 35.23 | 3 |
| FE (mg/L) | 0.02 | 0.02 | 0.02 | 0.02 | 0.00 | 3 |
| MN (mg/L) | 0.87 | 1.20 | 1.38 | 0.02 | 0.74 | 3 |
| SULFATE (mg/L) | 336.67 | 330 | 380 | 300 | 40.41 | 3 |
| TSS (mg/L) | 9.67 | 8 | 20 | 1 | 9.61 | 3 |

[1]SD: standard deviation, [2]N: number of sample measurements

**Table 2.4 In-stream Water Quality Data for Milepoint 0.62+0.15 (Sampled 1/96 – 3/96)**

| Mile 0.62+0.15 | Mean | Median | Max | Min | SD[1] | N[2] |
|---|---|---|---|---|---|---|
| FLOW (gpm) | 25.00 | 15 | 55 | 5 | 26.46 | 3 |
| TEMP (ºC) | 7.67 | 8 | 13 | 2 | 5.51 | 3 |
| PH | 7.17 | 7 | 7.5 | 7 | 0.29 | 3 |
| ACIDITY (mg/L $CaCO_3$) | 0 | 0 | 0 | 0 | 0 | 3 |
| ALKALINITY (mg/L $CaCO_3$) | 67.00 | 73 | 84 | 44 | 20.66 | 3 |
| CONDUCTIVITY (µmhos/cm) | 670.00 | 660 | 810 | 540 | 135.28 | 3 |
| TDS (mg/L) | 433.33 | 460 | 486 | 354 | 69.92 | 3 |
| FE (mg/L) | 0.09 | 0.11 | 0.14 | 0.02 | 0.06 | 3 |
| MN (mg/L) | 0.20 | 0.10 | 0.47 | 0.04 | 0.23 | 3 |
| SULFATE (mg/L) | 255.00 | 260 | 290 | 215 | 37.75 | 3 |
| TSS (mg/L) | 6.00 | 1 | 16 | 1 | 8.66 | 3 |

[1]SD: standard deviation, [2]N: number of sample measurements

**Table 2.5 In-stream Water Quality Data for Milepoint 1.34 (Sampled 12/92-3/96)**

| Mile 1.34 | Mean | Median | Max | Min | SD[1] | N[2] |
|---|---|---|---|---|---|---|
| FLOW (gpm) | 623.54 | 650 | 2,000 | 5 | 577.56 | 24 |
| TEMP (ºC) | 12.89 | 13 | 20 | 2 | 6.66 | 9 |
| PH | 7.08 | 7 | 8 | 6.5 | 0.33 | 24 |
| ACIDITY (mg/L $CaCO_3$) | 0 | 0 | 0 | 0 | 0 | 24 |
| ALKALINITY (mg/L $CaCO_3$) | 44.79 | 31 | 128 | 19 | 28.18 | 24 |
| CONDUCTIVITY (µmhos/cm) | 946.25 | 840 | 1,650 | 520 | 345.80 | 24 |
| TDS (mg/L) | 735.33 | 720 | 1,208 | 406 | 200.05 | 24 |
| FE (mg/L) | 0.92 | 0.74 | 2.93 | 0.01 | 0.83 | 24 |
| MN (mg/L) | 1.73 | 1.36 | 4.65 | 0.02 | 1.20 | 24 |
| SULFATE (mg/L) | 370.21 | 370 | 775 | 110 | 129.55 | 24 |
| TSS (mg/L) | 18.54 | 17 | 100 | 1 | 20.41 | 24 |

[1]SD: standard deviation, [2]N: number of sample measurements

**Table 2.6 In-stream Water Quality Data for Milepoint 2.09 (Sampled 2/96-6/99)**

| Mile 2.09 | Mean | Median | Max | Min | SD[1] | N[2] |
|---|---|---|---|---|---|---|
| FLOW (gpm) | 310.24 | 200 | 2,000 | 15 | 356.66 | 41 |
| TEMP (ºC) | 12.78 | 13 | 21 | 1 | 5.41 | 40 |
| PH | 6.81 | 7.2 | 8.3 | 4.2 | 1.13 | 39 |
| ACIDITY (mg/L $CaCO_3$) | 12.73 | 10 | 46 | 0 | 13.45 | 11 |
| ALKALINITY (mg/L $CaCO_3$) | 34.49 | 32 | 168 | 9 | 24.97 | 41 |
| CONDUCTIVITY (µmhos/cm) | 854.54 | 750 | 2,460 | 213 | 418.68 | 41 |
| TDS (mg/L) | 647.78 | 544 | 1,387 | 31 | 323.19 | 41 |
| FE (mg/L) | 1.09 | 0.4 | 7 | 0.2 | 1.71 | 39 |
| MN (mg/L) | 1.18 | 0.8 | 3.2 | 0.3 | 0.81 | 41 |
| SULFATE (mg/L) | 431.17 | 350 | 958 | 176 | 202.11 | 41 |
| TSS (mg/L) | 18.71 | 11 | 151 | 1 | 32.04 | 41 |

[1]SD: standard deviation, [2]N: number of sample measurements

**Table 2.7 In-stream Water Quality Data for Milepoint 2.10+0.04 (Sampled 12/92-3/96)**

| Mile 2.10+0.04 | Mean | Median | Max | Min | SD[1] | N[2] |
|---|---|---|---|---|---|---|
| FLOW (gpm) | 34.74 | 25 | 100 | 10 | 22.39 | 19 |
| TEMP (ºC) | 8.25 | 9 | 13 | 2 | 5.19 | 4 |
| PH | 7.46 | 7.5 | 8 | 6.2 | 0.38 | 19 |
| ACIDITY (mg/L $CaCO_3$) | 0 | 0 | 0 | 0 | 0 | 19 |
| ALKALINITY (mg/L $CaCO_3$) | 113.27 | 120 | 137 | 28.2 | 23.16 | 19 |
| CONDUCTIVITY (µmhos/cm) | 1,388.68 | 1,400 | 2,000 | 765 | 393.76 | 19 |
| TDS (mg/L) | 1,098.79 | 1,122 | 1,728 | 547 | 272.78 | 19 |
| FE (mg/L) | 0.18 | 0.06 | 1.81 | 0.02 | 0.40 | 19 |
| MN (mg/L) | 0.30 | 0.28 | 0.86 | 0.03 | 0.24 | 19 |
| SULFATE (mg/L) | 531.58 | 480 | 1450 | 100 | 262.85 | 19 |
| TSS (mg/L) | 12.05 | 8 | 104 | 1 | 22.94 | 19 |

[1]SD: standard deviation, [2]N: number of sample measurements

**Table 2.8 In-stream Water Quality Data for Milepoint 2.77 (Sampled 2/96-6/99)**

| Mile 2.77 | Mean | Median | Max | Min | SD[1] | N[2] |
|---|---|---|---|---|---|---|
| FLOW (gpm) | 368.80 | 250 | 1,950 | 1 | 424.87 | 41 |
| TEMP (ºC) | 13.23 | 14 | 21 | 1 | 5.39 | 40 |
| PH | 7.24 | 7.2 | 8.5 | 5.9 | 0.54 | 40 |
| ACIDITY (mg/L $CaCO_3$) | 7.45 | 10 | 12 | 0 | 4.82 | 11 |
| ALKALINITY (mg/L $CaCO_3$) | 37.48 | 38 | 82 | 8 | 14.02 | 42 |
| CONDUCTIVITY (µmhos/cm) | 894.45 | 861.5 | 2,360 | 230 | 389.76 | 42 |
| TDS (mg/L) | 676.81 | 667.5 | 1,345 | 40 | 302.49 | 42 |
| FE (mg/L) | 1.76 | 1.2 | 5.7 | 0.1 | 1.41 | 40 |
| MN (mg/L) | 1.53 | 1.1 | 4.4 | 0.1 | 1.10 | 41 |
| SULFATE (mg/L) | 443.74 | 437 | 888 | 40 | 191.93 | 42 |
| TSS (mg/L) | 22.76 | 17 | 107 | 1 | 21.79 | 42 |

[1]SD: standard deviation, [2]N: number of sample measurements

**Table 2.9 In-stream Water Quality Data for Milepoint 3.20+0.05 (Sampled 12/92-3/96)**

| Mile 3.20+0.05 | Mean | Median | Max | Min | SD[1] | N[2] |
|---|---|---|---|---|---|---|
| FLOW (gpm) | 12.21 | 10 | 30 | 1 | 9.44 | 19 |
| TEMP (ºC) | 8.25 | 9 | 13 | 2 | 5.19 | 4 |
| PH | 7.09 | 7.1 | 7.7 | 6.3 | 0.34 | 19 |
| ACIDITY (mg/L $CaCO_3$) | 0 | 0 | 0 | 0 | 0 | 19 |
| ALKALINITY (mg/L $CaCO_3$) | 167.26 | 213 | 384 | 64 | 90.38 | 19 |
| CONDUCTIVITY (µmhos/cm) | 1,134.74 | 1,100 | 2,000 | 510 | 447.29 | 19 |
| TDS (mg/L) | 868.68 | 873 | 1,288 | 344 | 306.22 | 19 |
| FE (mg/L) | 0.47 | 0.18 | 2.85 | 0.03 | 0.75 | 19 |
| MN (mg/L) | 1.99 | 1.12 | 8.28 | 0.1 | 2.21 | 19 |
| SULFATE (mg/L) | 401.74 | 400 | 640 | 73 | 139.50 | 19 |
| TSS (mg/L) | 7.53 | 6 | 26 | 1 | 7.16 | 19 |

[1]SD: standard deviation, [2]N: number of sample measurements

**Table 2.10 In-stream Water Quality Data for Milepoint 3.32 (Sampled 12/92-3/96)**

| Mile 3.32 | Mean | Median | Max | Min | SD[1] | N[2] |
|---|---|---|---|---|---|---|
| FLOW (gpm) | 281.00 | 250 | 1,000 | 10 | 253.06 | 20 |
| TEMP (ºC) | 11.60 | 12 | 25 | 2 | 8.73 | 5 |
| PH | 7.23 | 7.15 | 8.20 | 6.50 | 0.39 | 20 |
| ACIDITY (mg/L $CaCO_3$) | 0 | 0 | 0 | 0 | 0 | 20 |
| ALKALINITY (mg/L $CaCO_3$) | 36.90 | 38 | 68 | 19 | 11.03 | 20 |
| CONDUCTIVITY (µmhos/cm) | 492.50 | 440 | 860 | 340 | 152.70 | 20 |
| TDS (mg/L) | 300.80 | 296.50 | 514.00 | 194.00 | 78.04 | 20 |
| FE (mg/L) | 0.10 | 0.08 | 0.36 | 0.02 | 0.08 | 20 |
| MN (mg/L) | 0.12 | 0.10 | 0.32 | 0.02 | 0.09 | 20 |
| SULFATE (mg/L) | 170.75 | 150 | 320 | 0 | 69.55 | 20 |
| TSS (mg/L) | 9.00 | 4.5 | 53 | 1 | 12.56 | 20 |

[1]SD: standard deviation, [2]N: number of sample measurements

**Table 2.11 In-stream Water Quality Data for Milepoint 3.44 (Sampled 6/95-4/96)**

| Mile 3.44 | Mean | Median | Max | Min | SD[1] | N[2] |
|---|---|---|---|---|---|---|
| FLOW (gpm) | 275.40 | 39.58 | 763.01 | 23.61 | 422.36 | 3 |
| TEMP (ºC) | 9.70 | 9.70 | 10.40 | 9.00 | 0.99 | 2 |
| PH | 7.20 | 7.36 | 7.58 | 6.15 | 0.47 | 8 |
| ACIDITY (mg/L $CaCO_3$) | 0 | 0 | 0 | 0 | 0 | 4 |
| ALKALINITY (mg/L $CaCO_3$) | 69.75 | 61.5 | 100 | 56 | 20.34 | 4 |
| CONDUCTIVITY (µmhos/cm) | 823.43 | 816 | 889 | 747 | 43.82 | 7 |
| TDS (mg/L) | -- | -- | -- | -- | -- | -- |
| FE (mg/L) | 11.48 | 11.48 | 20.20 | 2.76 | 12.33 | 2 |
| MN (mg/L) | 2.37 | 2.37 | 2.37 | 2.36 | 0.01 | 2 |
| SULFATE (mg/L) | -- | -- | -- | -- | -- | -- |
| TSS (mg/L) | -- | -- | -- | -- | -- | -- |

[1]SD: standard deviation, [2]N: number of sample measurements, "—": insufficient data

#### *2.3.1.2 Water Quality Monitoring Conducted by Virginia Tech*

Data from in-stream benthic macroinvertebrate samples, collected during a Virginia Tech study, conducted by Professor Donald Cherry in the Black Creek Watershed, are available for August 1995 and October 1995. Figure 2.5 shows the locations of sample collections, with UBC-1 representing the location of the reference station. Samples were collected with a D-frame net, placed in a 500-ml Nalgene bottle, submerged with 70% alcohol for preservation, and then identified in the laboratory. In accordance with VADEQ methodologies, samples were analyzed at the family level to calculate 7 metrics (Tables 2.12 and 2.14). The metrics calculated for target stations (non-reference stations) were then compared to the metrics calculated for the reference station. For each metric, the ratio of the target metric to the reference metric was calculated, and a metric score (i.e. 0, 2, 4, or 6) was assigned based on a rule established for the particular metric. In the case of "Percent Contribution from Dominant Family" and "Community Loss Index" a scoring rule was applied based on the metric value at the target station, without comparison to the reference station metrics. The resulting metric scores (Tables 2.13 and

2.15) were then summed for each station, and a percentage comparison was calculated for each target station by dividing the summed metric score for the target station by the summed metric score for the reference station. A bioassessment rule was then applied to determine the bioassessment for the station (i.e. 0%-21%: Severely Impaired, 29%-72%: Moderately Impaired, 79%-100%: Non-Impaired).

As can be seen in tables 2.12 through 2.15, all stations on the mainstem of Black Creek were, at least, moderately impaired. One station on the mainstem (UBC-4) was identified as severely impaired in August 1995 and moderately impaired in October 1995. In addition, three of the tributaries (UD-1, UD-2, and UD-4) were observed as being severely impaired in October 1995.

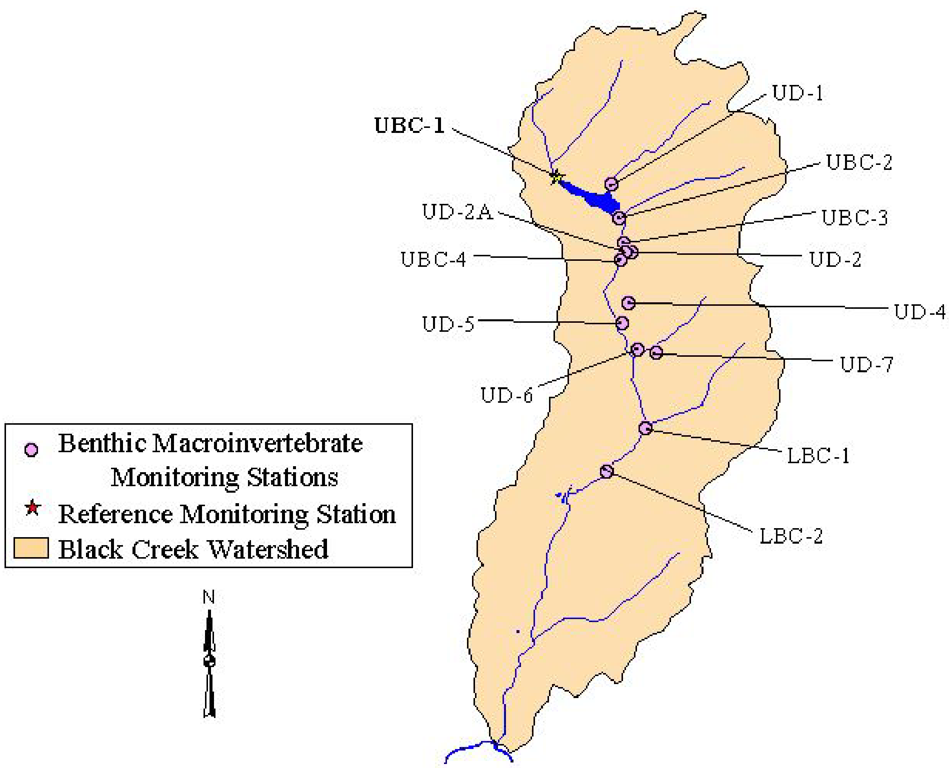


**Figure 2.5 Benthic Macroinvertebrate sampling conducted by Virginia Tech**

**Table 2.12 Comparison of Metric Values with the non-impaired reference station (UBC-1), data collected by Virginia Tech in August 1995.**

| Metrics [1] | UBC-1 | UD-1 | UBC-3 | UBC-4 | UD-5 | UD-7 | LBC-1 |
|---|---|---|---|---|---|---|---|
| TR | 12 | 8 | 5 | 4 | 2 | 6 | 8 |
| MFBI | 2.5 | 5.4 | 5.5 | 6 | 3.3 | 5 | 5.7 |
| SCR/FC | 0.4 | 0 | 0 | 0 | 0 | 0 | 0 |
| EPT/C | 9.43 | 2.59 | 6.5 | 6 | ERR[2] | 3.4 | 3.71 |
| % DT | 35.5 | 50 | 57.9 | 52.2 | 90 | 39.1 | 64.2 |
| EPTI | 5 | 3 | 3 | 1 | 1 | 4 | 3 |
| CLI | 0 | 0.5 | 1.4 | 2 | 5 | 1.3 | 0.8 |

[1]TR: taxa richness, MFBI: Modified Family Biotic Index, SCR/FC: Scraper/Filter Collector ratio, EPT/C: EPT/Chironomidae, %DT: percent Dominant Taxon, EPTI: EPT Index, CLI: Community Loss Index
[2]ERR: not calculable

**Table 2.13 Comparison of Bioassessment Scores with the non-impaired reference station (UBC-1), data collected by Virginia Tech in August 1995.**

| | Bioassessment Score | | | | | | |
|---|---|---|---|---|---|---|---|
| **Metrics[1]** | **UBC-1** | **UD-1** | **UBC-3** | **UBC-4** | **UD-5** | **UD-7** | **LBC-1** |
| TR | 6 | 4 | 2 | 0 | 0 | 2 | 4 |
| MFBI | 6 | 0 | 0 | 0 | 4 | 2 | 0 |
| SCR/FC | 6 | 0 | 0 | 0 | 0 | 0 | 0 |
| EPT/C | 6 | 2 | 4 | 4 | 6 | 2 | 2 |
| % DT | 2 | 0 | 0 | 0 | 0 | 2 | 0 |
| EPTI | 6 | 0 | 0 | 0 | 0 | 4 | 0 |
| CLI | 6 | 4 | 4 | 2 | 0 | 4 | 4 |
| Total Score | 38 | 10 | 10 | 6 | 10 | 16 | 10 |
| % Comp to UBC-1 | n/a | 26.3 | 26.3 | 15.8 | 26.3 | 42.1 | 26.3 |
| Biological Condition[2] | NI | MI | MI | SI | MI | MI | MI |

[1]TR: taxa richness, MFBI: Modified Family Biotic Index, SCR/FC: Scraper/Filter Collector ratio, EPT/C: EPT/Chironomidae, %DT: percent Dominant Taxon, EPTI: EPT Index, CLI: Community Loss Index
[2]NI: not impaired, SI: severely impaired, MI: moderately impaired
n/a: not applicable

**Table 2.14 Comparison of Metric Values with the Non-impaired Reference Station (UBC-1), data collected by Virginia Tech in October 1995.**

| Metrics[1] | UBC-1 | UD-1 | UBC-2 | UD-2 | UD-2A | UBC-3 | UBC-4 | UD-4 | LBC-1 | LBC-2 |
|---|---|---|---|---|---|---|---|---|---|---|
| TR | 11 | 5 | 4 | 2 | 1 | 3 | 3 | 2 | 8 | 2 |
| MFBI | 2.4 | 5.1 | 5.7 | 5.1 | 4 | 4.8 | 4.8 | 5.7 | 4.3 | 1.5 |
| SCR/FC | 21 | 0 | ERR[2] | ERR | ERR | ERR | ERR | ERR | 0 | ERR |
| EPT/C | 41.5 | 0.02 | 0 | 0 | ERR | 0 | 0 | 0 | 1.88 | ERR |
| % DT | 34.2 | 57.3 | 74.8 | 57.1 | 100 | 45.9 | 46.7 | 86.4 | 28.7 | 50 |
| EPTI | 4 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 1 |
| CLI | 0 | 1.6 | 2 | 5 | 11 | 3 | 3 | 5 | 0.8 | 4.5 |

[1]TR: taxa richness, MFBI: Modified Family Biotic Index, SCR/FC: Scraper/Filter Collector ratio, EPT/C: EPT/Chironomidae, %DT: percent Dominant Taxon, EPTI: EPT Index, CLI: Community Loss Index
[2]ERR: not calculable

**Table 2.15 Comparison of Bioassessment Scores with the Non-Impaired Reference Station (UBC-1), data collected by Virginia Tech in October 1995.**

| | Bioassessment Score | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Metrics[1] | UBC-1 | UD-1 | UBC-2 | UD-2 | UD-2A | UBC-3 | UBC-4 | UD-4 | LBC-1 | LBC-2 |
| TR | 6 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0 |
| MFBI | 6 | 0 | 0 | 0 | 2 | 2 | 2 | 0 | 2 | 6 |
| SCR/FC | 6 | 0 | 6 | 6 | 6 | 6 | 6 | 6 | 0 | 6 |
| EPT/C | 6 | 0 | 0 | 0 | 6 | 0 | 0 | 0 | 0 | 6 |
| % DT | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0 |
| EPTI | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 |
| CLI | 6 | 2 | 2 | 0 | 0 | 2 | 2 | 0 | 4 | 0 |
| Total Score | 38 | 4 | 8 | 6 | 14 | 10 | 10 | 6 | 16 | 18 |
| % Comp to UBC-1 | n/a | 10.5 | 21.1 | 15.8 | 36.8 | 26.3 | 26.3 | 15.8 | 42.1 | 47.4 |
| Biological Condition[2] | NI | SI | MI | SI | MI | MI | MI | SI | MI | MI |

[1]TR: taxa richness, MFBI: Modified Family Biotic Index, SCR/FC: Scraper/Filter Collector ratio, EPT/C: EPT/Chironomidae, %DT: percent Dominant Taxon, EPTI: EPT Index, CLI: Community Loss Index
[2]NI: not impaired, SI: severely impaired, MI: moderately impaired
n/a=not applicable

Cherry (1997) also reported data from chemical/physical monitoring that was performed in the watershed as part of his study. The location of sampling stations is presented in Figure 2.6. The concentration of metals at various points in the watershed is presented in Tables 2.16 and 2.17. Sampling for metals was conducted in October and November 1995. Samples were analyzed for total aluminum, total iron, total manganese, total copper, total zinc, and total magnesium. Tables 2.17 through 2.23 report statistical summaries of pH, conductivity, acidity, and alkalinity measured at various points in the watershed. Flow and temperature measurements collected during Professor Cherry's study are reported in tables 2.22 and 2.23, respectively. Sample stations denoted as either "UD" or "LD" represent tributaries to Black Creek or mine seeps (i.e. UD-1 and LD-1 are stations on tributaries to Black Creek). It is difficult to draw many conclusions from this amount of data, however, it is fairly evident that samples from mine seeps tend to be higher in acidity, conductivity, and metal concentrations; and lower in pH, and alkalinity.

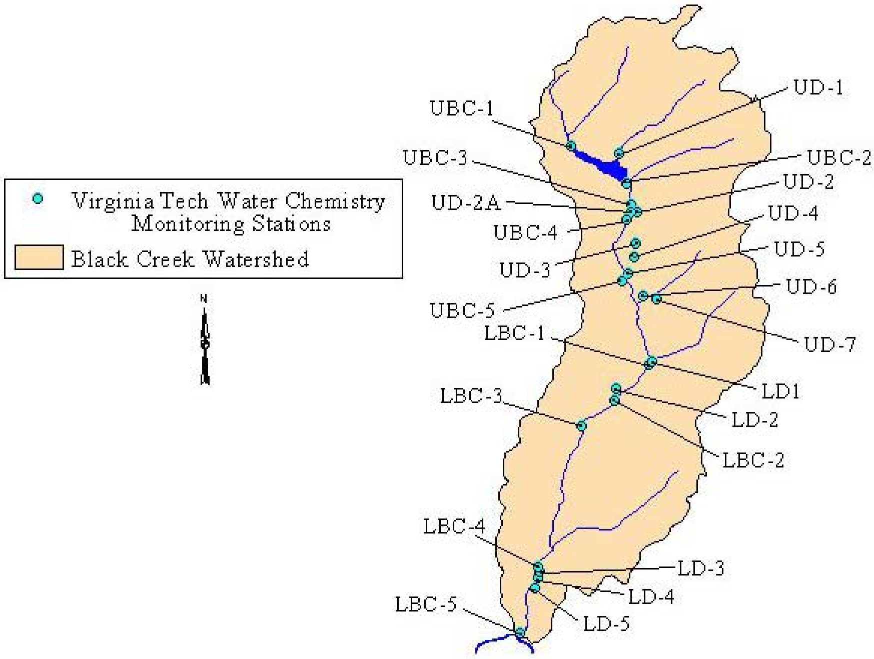


**Figure 2.6 Water chemistry sampling conducted by Virginia Tech**

**Table 2.16 Metal analysis of water samples collected by Virginia Tech at selected Black Creek sites in October 1995**

| Site | Aluminum (mg/L) | Iron (mg/L) | Manganese (mg/L) | Copper (mg/L) | Zinc (mg/L) | Magnesium (mg/L) |
|---|---|---|---|---|---|---|
| UBC-1 | 0.486 | 0.237 | 0.064 | 0.012 | 0.017 | 23.9 |
| UD-1 | 0.521 | 2.76 | 2.36 | 0.002 | BDL | 51.2 |
| UD-3 | 0.521 | 0.121 | 0.004 | BDL[1] | BDL | 51.8 |
| UD-2 | 12.7 | 0.204 | 2.38 | 0.023 | 0.285 | 117 |
| UD-2A | 11.2 | 2.49 | 2.64 | 0.019 | 0.257 | 116 |
| UBC-3 | 2.12 | 1.31 | 1.27 | BDL | 0.053 | 58.9 |
| UBC-4 | 6.54 | 1.87 | 2.01 | 0.004 | 0.175 | 85.9 |
| UD-4 | 31.9 | 22.9 | 5.71 | BDL | 0.459 | 107 |
| UD-5 | 31.7 | 6.75 | 4.26 | 0.004 | 0.435 | 104 |
| UD-6 | 0.556 | 14.3 | 2.99 | BDL | BDL | 35.9 |
| UD-7 | 1.08 | 11 | 3.49 | BDL | 0.018 | 48.1 |

[1]BDL= below detection limit

**Table 2.17 Metal analysis of water samples collected by Virginia Tech at selected Black Creek sites in November 1995**

| Site | Aluminum (mg/L) | Iron (mg/L) | Manganese (mg/L) | Copper (mg/L) | Zinc (mg/L) | Magnesium (mg/L) |
|---|---|---|---|---|---|---|
| UBC-1 | 0.25 | 0.39 | BDL[1] | BDL | BDL | 16.5 |
| UD-1 | 0.73 | 20.2 | 2.37 | BDL | BDL | 28.5 |
| UD-1A | 0.77 | 0.39 | 3.71 | BDL | 0.05 | 24 |
| UD-2 | 10.1 | 0.17 | 1.87 | BDL | 0.23 | 74 |
| UD-2A | 2.31 | 0.47 | 1.86 | BDL | 0.08 | 49 |
| UD-4 | 28.1 | 11.3 | 5.31 | BDL | 0.34 | 81 |
| UD-5 | 22.3 | 13.6 | 2.01 | BDL | 0.3 | 55 |
| UD-6 | 0.94 | 8.98 | 2.82 | BDL | 0.02 | 23.5 |
| UD-7 (at road) | 14.7 | 3.25 | 2.22 | BDL | 0.27 | 130 |
| UD-7 (at source) | 0.55 | 3.59 | 6.75 | BDL | 0.05 | 33 |

[1]BDL= below detection limit

**Table 2.18 Measurements of pH from water samples collected by Virginia Tech at selected Black Creek Sites (Sampled 6/95-4/96)**

| Site | Mean (su) | Median (su) | Max (su) | Min (su) | N[1] |
|---|---|---|---|---|---|
| UBC-1 | 7.12 | 6.98 | 7.84 | 6.69 | 9 |
| UBC-2 | 7.22 | 7.24 | 7.28 | 7.14 | 3 |
| UBC-3 | 6.73 | 6.77 | 7.03 | 6.43 | 7 |
| UBC-4 | 5.62 | 5.88 | 6.30 | 4.70 | 7 |
| UBC-5 | 6.13 | -- | -- | -- | 1 |
| UD-1 | 7.21 | 7.39 | 7.58 | 6.15 | 8 |
| UD-2 | 3.69 | 3.66 | 4.40 | 3.37 | 9 |
| UD-2A | 4.15 | 4.06 | 4.78 | 3.62 | 8 |
| UD-3 | 3.95 | 4.01 | 4.56 | 3.20 | 4 |
| UD-4 | 4.01 | 3.39 | 5.84 | 3.10 | 7 |
| UD-5 | 3.12 | 3.14 | 3.60 | 2.75 | 8 |
| UD-6 | 6.98 | 7.14 | 7.67 | 6.21 | 8 |
| UD-7 | 4.55 | 3.88 | 6.46 | 3.10 | 6 |
| LBC-1 | 7.13 | 7.27 | 7.81 | 6.10 | 7 |
| LBC-2 | 6.98 | 6.98 | 7.33 | 6.63 | 2 |
| LBC-3 | 6.79 | 6.79 | 7.03 | 6.54 | 2 |
| LBC-4 | 7.15 | -- | -- | -- | 1 |
| LBC-5 | 7.68 | 7.79 | 7.93 | 7.30 | 6 |
| LD-1 | 7.26 | 7.26 | 7.48 | 7.04 | 2 |
| LD-2 | 6.34 | 6.05 | 7.10 | 5.86 | 3 |
| LD-3 | 6.66 | 6.81 | 7.30 | 5.72 | 4 |
| LD-4 | 6.60 | -- | -- | -- | 1 |
| LD-5 | 6.93 | -- | -- | -- | 1 |

[1]N: number of samples, where sample size is equal to one, the value of the sample is reported in the "Mean" column.

**Table 2.19 Conductivity measurements of water samples collected by Virginia Tech at selected Black Creek sites (Sampled 6/95-4/96)**

| Site | Mean (µmhos/cm) | Median (µmhos/cm) | Max (µmhos/cm) | Min (µmhos/cm) | N[1] |
|---|---|---|---|---|---|
| UBC-1 | 375 | 422 | 518 | 196 | 8 |
| UBC-2 | 451 | 392 | 592 | 369 | 3 |
| UBC-3 | 728 | 664 | 1,107 | 542 | 7 |
| UBC-4 | 938 | 845 | 1,435 | 650 | 7 |
| UBC-5 | 647 | -- | -- | -- | 1 |
| UD-1 | 823 | 816 | 889 | 747 | 7 |
| UD-2 | 1,578 | 1,545 | 1,864 | 1,347 | 8 |
| UD-2A | 1,453 | 1,483 | 1,795 | 1,087 | 7 |
| UD-3 | 1,011 | 1,016 | 1,088 | 929 | 3 |
| UD-4 | 1,488 | 1,502 | 1,938 | 1,048 | 6 |
| UD-5 | 1,854 | 1,835 | 2,040 | 1,622 | 7 |
| UD-6 | 837 | 848 | 865 | 800 | 7 |
| UD-7 | 1,449 | 1,680 | 1,980 | 745 | 5 |
| LBC-1 | 1,084 | 1,269 | 1,376 | 738 | 7 |
| LBC-2 | 815 | 815 | 820 | 809 | 2 |
| LBC-3 | 1,012 | 1,012 | 1,222 | 802 | 2 |
| LBC-4 | 787 | 787 | 794 | 780 | 2 |
| LBC-5 | 825 | 780 | 957 | 750 | 5 |
| LD-1 | 1,036 | 1,036 | 1,203 | 868 | 2 |
| LD-2 | 959 | 930 | 1,067 | 881 | 3 |
| LD-3 | 685 | 610 | 1,050 | 395 | 3 |
| LD-4 | 829 | 862 | 912 | 712 | 3 |
| LD-5 | 1,057 | -- | -- | -- | 1 |

[1]N: number of samples, where sample size is equal to one, the value of the sample is reported in the "Mean" column, "--" insufficient data

**Table 2.20 Acidity measurements of water samples collected by Virginia Tech at selected Black Creek sites (Sampled 8/95-3/96)**

| Site | Mean (mg/L $CaCO_3$) | Median (mg/L $CaCO_3$) | Max (mg/L $CaCO_3$) | Min (mg/L $CaCO_3$) | N[1] |
|---|---|---|---|---|---|
| UBC-3 | 22 | 15 | 35 | 15 | 3 |
| UBC-4 | 25 | 25 | 40 | 10 | 2 |
| UD-2 | 100 | 98 | 118 | 85 | 4 |
| UD-2A | 91 | 93 | 113 | 67 | 3 |
| UD-3 | 942 | 942 | 1,800 | 83 | 2 |
| UD-4 | 778 | 336 | 1,785 | 213 | 3 |
| UD-5 | 292 | 299 | 334 | 235 | 4 |

[1]N: number of samples, where sample size is equal to one, the value of the sample is reported in the "Mean" column, "--" insufficient data

**Table 2.21 Alkalinity measurements of water samples collected by Virginia Tech at selected Black Creek sites (Sampled 8/95-3/96)**

| Site | Mean (mg/L $CaCO_3$) | Median (mg/L $CaCO_3$) | Max (mg/L $CaCO_3$) | Min (mg/L $CaCO_3$) | N[1] |
|---|---|---|---|---|---|
| UBC-1 | 74 | 59 | 150 | 27 | 4 |
| UBC-2 | 30 | -- | -- | -- | 1 |
| UBC-5 | 24 | -- | -- | -- | 1 |
| UD-1 | 70 | 62 | 100 | 56 | 4 |
| UD-6 | 165 | 155 | 200 | 149 | 4 |
| UD-7 | 131 | -- | -- | -- | 1 |
| LBC-1 | 68 | 68 | 86 | 50 | 2 |
| LBC-3 | 56 | -- | -- | -- | 1 |
| LBC-5 | 47 | 47 | 50 | 43 | 2 |
| LD-2 | 117 | -- | -- | -- | 1 |

[1]N: number of samples, where sample size is equal to one, the value of the sample is reported in the "Mean" column,
"--" insufficient data

**Table 2.22 Flow measurements (L/s) conducted by Virginia Tech at selected Black Creek sites on four different sample dates**

| Sites | 8/31/95 | 2/13/96 | 3/7/96 | 4/2/96 |
|---|---|---|---|---|
| UBC-1 | 0.4 | 39.4 | * | 1.5 |
| UBC-2 | * | * | * | 0.9 |
| UD-1 | 2.5 | 1.5 | * | 1.7 |
| UD-2 | * | 0.74 | 3.3 | 0.75 |
| UD-2A | 2.3 | * | * | * |
| UD-3 | * | 0.88 | 2.74 | 0.66 |
| UD-4 | * | 0.38 | 1.7 | * |
| UD-5 | * | 0.19 | 1.9 | 0.24 |
| UD-6 | 4.9 | 1.8 | 5.4 | 1.45 |
| UD-7 | * | 0.32 | 4.7 | 0.46 |
| LD-2 | * | * | 2.3 | 0.64 |
| LBC-1 | 0.5 | 219 | * | * |
| LBC-5 | * | 386 | * | 8.2 |
| LD-3 | * | * | 4.2 | 0.32 |
| LD-4 | * | * | 2.5 | 0.1 |

"*" no data

**Table 2.23 Temperature measurements (ºC) conducted by Virginia Tech at selected Black Creek sites on two different sample dates**

| Sites | 3/13/96 | 4/2/96 |
|---|---|---|
| UBC-1 | 5.6 | 7.2 |
| UBC-2 | 6.1 | 10.3 |
| UBC-3 | 7.1 | * |
| UBC-4 | 7.8 | * |
| UBC-5 | 8.4 | * |
| UD-1 | 9.7 | 10.4 |
| UD-2 | 12.5 | 12.6 |
| UD-2A | 11.8 | 12.7 |
| UD-3 | 8.6 | 10.5 |
| UD-4 | 13.6 | 15 |
| UD-5 | 16.8 | 15.6 |
| UD-6 | 12.7 | 13.9 |
| UD-7 | * | 11.9 |
| LD-2 | 14.3 | 17.6 |
| LBC-1 | 9.9 | * |
| LBC-2 | * | 14.9 |
| LBC-3 | 11.7 | 12.9 |
| LBC-4 | * | 12.8 |
| LBC-5 | 8.3 | 10.6 |
| LD-3 | * | 13.1 |
| LD-4 | * | 10.3 |
| LD-5 | * | 10.9 |

"*" no data

#### *2.3.1.3 Water Quality Monitoring Conducted by VADMME*

The Virginia Department of Mines, Minerals and Energy arranged for additional benthic macroinvertebrate samples to be collected by Environmental Services & Consulting, LLC, (ES&C) at three stations in the Black Creek Watershed, on October 9, 2001. The sampling stations corresponded to stations used by Professor Cherry in his study and share the labeling scheme used by Cherry (Figure 2.7). Station UBC-1 is the reference station. Station LBC-4 is downstream of two wetlands established in 1999 to aid in reclamation of the stream. Station LBC-5 is at the outlet of Black Creek. As reported by ES&C, the samples were collected following the USEPA RBP II (family level) survey. Samples were collected with a square framed dip net with 500-micron mesh. Samples were preserved in 70% ethanol and returned to the lab for analysis. The multi-habitat approach was used to collect a composite sample of the available habitat types within each reach. The following modification for processing the sample was made. Instead of sub-sampling the un-processed sample and picking invertebrates from only a portion of the original sample, ES&C picked the entire sample allowing for the better preservation of all insects and further study if needed. After removing all the insects they were redistributed in a pan of water and re-picked without the detritus present to achieve the macroinvertebrate sub sample used for identification. All macroinvertebrates were preserved in 70% ethanol. The results of the analysis are presented in Table 2.24.

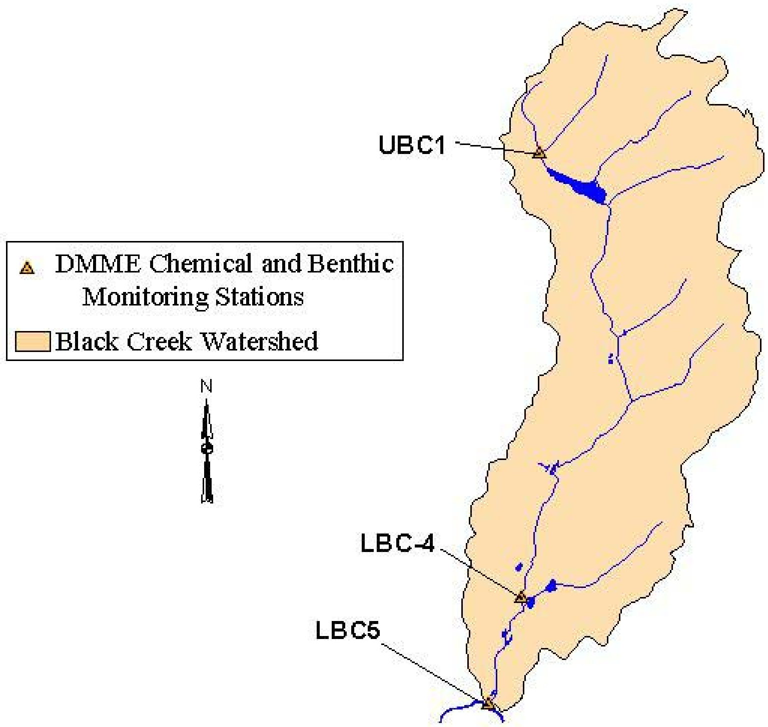


**Figure 2.7 Benthic Macroinvertebrate and Water Chemistry Sampling Conducted by DMME on October 9, 2001**

**Table 2.24 Comparison of Metric Values between Three Benthic Macroinvertebrate Sample Stations (Samples collected by ES&C, 10/9/ 2001)**

| Metrics[1] | UBC-1 | LBC-4 | LBC-5 |
|---|---|---|---|
| TR | 19 | 8 | 12 |
| MFBI | 2.9 | 2.9 | 4.4 |
| SCR/FC | 0.0454 | 0 | 0.0005 |
| EPT/C | 1.213 | 0 | 5.545 |
| % DT | 36.095 | 63.855 | 31.923 |
| EPTI | 8 | 3 | 5 |
| CLI | 0 | 1.875 | 1 |

[1]TR: taxa richness, MFBI: Modified Family Biotic Index, SCR/FC: Scraper/Filter Collector ratio, EPT/C: EPT/Chironomidae, %DT: percent Dominant Taxon, EPTI: EPT Index, CLI: Community Loss Index

MapTech personnel used the metric data supplied by ES&C to calculate metric scores and corresponding bioassessments (Table 2.25). The overall bioassessment at the two target sites is comparable to the assessments developed by Professor Cherry in 1995 (i.e. moderately impaired) and the percentage comparisons to the reference station are also comparable to those calculated by Cherry for stations in the lower section of Black Creek.

**Table 2.25 Comparison of Bioassessment Scores with the non-impaired reference station (UBC-1), data collected by ES&C (10/ 9/2001).**

| | Bioassessment Score | | |
|---|---|---|---|
| **Metrics[1]** | **UBC-1** | **LBC-4** | **LBC-5** |
| TR | 6 | 3 | 3 |
| MFBI | 6 | 6 | 3 |
| SCR/FC | 6 | 0 | 0 |
| EPT/C | 6 | 0 | 6 |
| % DT | 3 | 0 | 3 |
| EPTI | 6 | 0 | 0 |
| CLI | 6 | 3 | 3 |
| Total Score | 39 | 12 | 18 |
| % Comp to UBC-1 | n/a | 30.8 | 46.2 |
| Biological Condition[2] | NI | MI | MI |

[1]TR: taxa richness, MFBI: Modified Family Biotic Index, SCR/FC: Scraper/Filter Collector ratio, EPT/C: EPT/Chironomidae, %DT: percent Dominant Taxon, EPTI: EPT Index, SHR/T: Shredder/Total Abundance ratio, CLI: Community Loss Index
n/a: not applicable
[2]NI: not impaired, SI: severely impaired, MI: moderately impaired

Concurrent with sampling of the benthic macroinvertebrate community, water chemistry samples were collected and analyzed by Environmental Monitoring Incorporated (EMI) for measurement of chemical/physical properties in the water column where the biological samples were collected. Results of monitoring are presented in Table 2.26. It is impossible to make significant observations based on a single sampling event, however, the measurements made are in general agreement with those presented in Section 2.3.1.1.

**Table 2.26 Water Chemistry Data Sampled by DMME on 10/9/2001**

| Parameter | UBC-1 | LBC-4 | LBC-5 | MDL[2] |
|---|---|---|---|---|
| Iron, dissolved (mg/L) | 0.06 | 0.16 | 0.02 | 0.020 |
| Manganese, dissolved (mg/L) | BDL[1] | 1.4 | 0.69 | 0.020 |
| Acidity (mg/L CaCO3) | BDL | BDL | BDL | 1.00 |
| Alkalinity (mg/L CaCO3) | 51 | 53 | 58 | 1.00 |
| Conductivity (µmhos/cm) | 340 | 1,300 | 1,320 | 0.800 |
| PH | 7 | 7.1 | 7.5 | n/a |
| Sulfate (mg/L) | 149 | 548 | 634 | 1.00 |
| Total Dissolved Solids (mg/L) | 275 | 1,000 | 1,145 | 6.00 |
| Total Suspended Solids (mg/L) | BDL | BDL | BDL | 4.00 |
| Iron, total (mg/L) | 8.4 | 0.26 | 21.2 | 0.020 |
| Manganese, total (mg/L) | 0.08 | 1.41 | 0.84 | 0.020 |

[1]BDL: Below Detection Limit, [2]MDL: Minimum Detection Limit, n/a: not applicable

## 2.3.2 Trend and Seasonal Analyses

In order to improve TMDL allocation scenarios and, therefore, the success of implementation strategies, trend and seasonal analyses were performed on precipitation, flow rates, and metals concentrations. A Seasonal Kendall Test was used to examine long-term trends (Gilbert, 1987). The Seasonal Kendall Test ignores seasonal cycles when looking for long-term trends. This improves the chances of finding existing trends in data that are likely to have seasonal patterns. Additionally, trends for specific seasons can be analyzed. For instance, the Seasonal Kendall Test can identify the trend (over many years) in discharge levels during a particular season or month.

A seasonal analysis of precipitation, flow rates, and metals concentration data was conducted using the Moods Median Test (MINITAB, 1995). This test was used to compare median values of flow and metal concentrations in each month. Significant differences between months within years were reported.

### *2.3.2.1 Precipitation*

Total monthly precipitation measured in Wise, Virginia from May 1955 to August 2000, was analyzed, and no overall, long-term trend was found. Differences in mean monthly precipitation at Wise are indicated in Table 2.27. Precipitation values in months with the same median group letter are not significantly different from each other at the 95% significance level. For example, January, September, October, November and December are all in median group "A" and are not significantly different from each other. In general, precipitation in the spring-summer months tends to be higher than precipitation in the fall-winter months.

**Table 2.27 Summary of Moods Median Test on mean monthly precipitation at Wise, Virginia**

| Month | Mean (in) | Minimum (in) | Maximum (in) | Median Groups[1] | | |
|---|---|---|---|---|---|---|
| January | 3.71 | 1.13 | 8.47 | A | B | |
| February | 3.82 | 0.62 | 8.93 | | B | |
| March | 4.42 | 1.94 | 10.78 | | B | C |
| April | 4.07 | 1.00 | 9.59 | | B | C |
| May | 4.28 | 1.79 | 8.49 | | B | C |
| June | 3.91 | 0.72 | 11.61 | | B | |
| July | 5.17 | 1.05 | 11.07 | | | C |
| August | 3.92 | 0.33 | 7.96 | | B | |
| September | 3.49 | 0.87 | 7.52 | A | B | |
| October | 2.84 | 0.03 | 6.58 | A | | |
| November | 3.56 | 1.38 | 6.38 | A | B | |
| December | 3.54 | 0.42 | 7.22 | A | B | |

[1]Precipitation in months with the same median group letter is not significantly different from each other at the 95% level of significance.

### *2.3.2.2 In-Stream Monitoring Stations*

In-stream water samples were collected at selected milepoints on Black Creek. Monthly averages of flow rates and metals concentrations were calculated for each sampling month. Table 2.28 shows the milepoints and the time periods over which samples were collected and analyzed. The only milepoints with enough samples to conduct trend and seasonal analyses were milepoints 0.13, 2.09 and 2.77.

Trend analyses were conducted on the monthly average flow rates and metals concentrations at milepoints 0.13, 2.09 and 2.77. No overall long-term trend was found at any of these milepoints for any constituent. Differences were found between months for flow at milepoints 0.13 and 2.09, and for manganese and temperature at milepoints 2.09 and 2.77.

**Table 2.28 Locations and Time Periods over which water samples were collected in Black Creek**

| Milepoint | Sampling Time Period |
|---|---|
| 0.01 | No Data |
| 0.05 | July 1995 – March 1996 |
| 0.13 | November 1996 – March 1999 |
| 0.43 | January 1996 – March 1996 |
| 0.62+0.15 | January 1996 – March 1996 |
| 1.34 | December 1992 – March 1996 |
| 1.45 | No Data |
| 2.09 | February 1996 – June 1999 |
| 2.10+0.04 | December 1992 – March 1996 |
| 2.60 | No Data |
| 2.77 | February 1996 – June 1999 |
| 3.20+0.05 | December 1992 – March 1996 |
| 3.32 | December 1992 – March 1996 |
| 3.44 | June 1995 – April 1996 |

Differences in mean monthly flow at milepoint 0.13 are indicated in Table 2.29. Differences in mean monthly flow at milepoint 2.09 are indicated in Table 2.30. Flow rates in months with the same median group letter are not significantly different from each other. In general, flow rates in the fall-winter months tend to be lower than flow rates in the spring-summer months.

**Table 2.29 Summary of Moods Median Test on mean monthly flow rate at Black Creek, milepost 0.13**

| Month | Mean (gpm) | Minimum (gpm) | Maximum (gpm) | Median Groups | | |
|---|---|---|---|---|---|---|
| January | 5,333.33 | 4,000 | 7,500 | | B | |
| February | 7,633.33 | 6,000 | 10,000 | | B | C |
| March | 6800 | 6,000 | 7,600 | | B | C |
| April | 9450 | 6,500 | 17,000 | | B | C |
| May | 12,100 | 5,200 | 19,000 | | | C |
| June | 8,750 | 6,500 | 11,000 | | | C |
| July | 3,750 | 2,000 | 5,500 | A | | |
| August | 3,750 | 2,000 | 5,500 | A | | |
| September | 8,150 | 6,300 | 10,000 | | | C |
| October | 2,500 | 2,000 | 3,000 | A | | |
| November | 1,533.33 | 500 | 3,000 | A | | |
| December | 2,866.67 | 1,100 | 5,000 | A | | |

**Table 2.30 Summary of Moods Median Test on mean monthly flow rate at Black Creek, milepoint 2.09**

| Month | **Mean (gpm)** | **Minimum (gpm)** | **Maximum (gpm)** | **Median Groups** | | |
|---|---|---|---|---|---|---|
| January | 366.67 | 350 | 400 | | B | |
| February | 818.75 | 125 | 2,000 | | | C |
| March | 443.75 | 100 | 1,000 | | B | |
| April | 193.75 | 75 | 400 | | B | |
| May | 312.5 | 100 | 500 | | B | |
| June | 391.25 | 15 | 900 | | B | |
| July | 175 | 125 | 200 | A | | |
| August | 123.33 | 95 | 175 | A | | |
| September | 56.66 | 40 | 80 | A | | |
| October | 61.66 | 30 | 110 | A | | |
| November | 261.66 | 35 | 450 | | B | C |
| December | 315 | 70 | 475 | | B | C |

Differences in mean monthly manganese at milepoint 2.09 are indicated in Table 2.31. Differences in mean monthly manganese at milepoint 2.77 are indicated in Table 2.32. Manganese concentrations in months with the same median group letter are not significantly different from each other. In general, manganese concentrations in the fall months tend to be higher. This time period corresponds to low-flow conditions (Table 2.9) and may indicate that the predominant sources on manganese are not storm-flow dependent (AMD, and groundwater).

**Table 2.31 Summary of Moods Median Test on mean monthly manganese at Black Creek, milepost 2.09**

| **Month** | **Mean (mg/L)** | **Minimum (mg/L)** | **Maximum (mg/L)** | **Median Groups** | | |
|---|---|---|---|---|---|---|
| January | 0.867 | 0.6 | 1.2 | | B | |
| February | 0.55 | 0.3 | 0.7 | A | | |
| March | 0.675 | 0.3 | 1.2 | A | B | |
| April | 0.575 | 0.4 | 0.8 | A | | |
| May | 0.525 | 0.3 | 0.7 | A | | |
| June | 0.975 | 0.4 | 1.5 | A | B | |
| July | 1.033 | 0.8 | 1.4 | | B | |
| August | 1.533 | 0.8 | 1.9 | | B | |
| September | 2.467 | 2.3 | 2.8 | | | C |
| October | 2.466 | 1.9 | 2.8 | | | C |
| November | 1.7 | 1.1 | 2.7 | | B | C |
| December | 1.633 | 0.8 | 3.2 | | B | C |

**Table 2.32 Summary of Moods Median Test on mean monthly manganese at Black Creek, milepost 2.77**

| Month | Mean (mg/L) | Minimum (mg/L) | Maximum (mg/L) | Median Groups | |
|---|---|---|---|---|---|
| January | 1.4 | 0.5 | 2.7 | A | |
| February | 0.75 | 0.4 | 1.1 | A | |
| March | 0.8 | 0.6 | 1 | A | |
| April | 1.1 | 0.8 | 1.3 | A | |
| May | 0.9 | 0.6 | 1.1 | A | |
| June | 1.53 | 0.9 | 2.4 | A | |
| July | 0.97 | 0.1 | 1.5 | A | |
| August | 1.77 | 0.1 | 2.7 | A | |
| September | 3.33 | 2.9 | 3.7 | | B |
| October | 3.27 | 2.5 | 4.4 | | B |
| November | 2.3 | 0.8 | 4.2 | | B |
| December | 0.85 | 0.4 | 1.3 | A | |

Differences in mean monthly temperature at milepoint 2.09 are indicated in Table 2.33. Differences in mean monthly temperature at milepoint 2.77 are indicated in Table 2.34. Temperatures in months with the same median group letter are not significantly different from each other. In general, temperatures in the spring-summer months tend to be higher than temperatures in the fall-winter months. This seasonal trend was expected. The lack of a significant trend at milepoint 0.13 is probably due to the timing of samples rather than the lack of a trend.

**Table 2.33 Summary of Moods Median Test on mean monthly temperature at Black Creek, milepost 2.09**

| Month | Mean (ºC) | Minimum (ºC) | Maximum (ºC) | Median Groups | | | |
|---|---|---|---|---|---|---|---|
| January | 4.33 | 1 | 7 | A | | | |
| February | 6.67 | 5 | 8 | A | | | |
| March | 8.25 | 6 | 11 | A | B | | |
| April | 12 | 9 | 15 | | B | | |
| May | 16.5 | 12 | 20 | | B | C | |
| June | 17.75 | 16 | 19 | | | C | |
| July | 20.67 | 20 | 21 | | | | D |
| August | 16.33 | 15 | 18 | | | C | |
| September | 18 | 16 | 20 | | | C | |
| October | 14.33 | 13 | 16 | | B | | |
| November | 8.33 | 5 | 11 | A | | | |
| December | 9 | 6 | 11 | A | | | |

**Table 2.34 Summary of Moods Median Test on mean monthly temperature at Black Creek, milepost 2.77**

| Month | Mean (ºC) | Minimum (ºC) | Maximum (ºC) | Median Groups | | |
|---|---|---|---|---|---|---|
| January | 4.33 | 1 | 7 | A | | |
| February | 6.33 | 5 | 7 | A | | |
| March | 8.5 | 6 | 11 | | B | |
| April | 12.25 | 9 | 15 | | B | |
| May | 16.75 | 12 | 21 | | B | C |
| June | 18.25 | 17 | 20 | | | C |
| July | 20 | 19 | 21 | | | C |
| August | 17.5 | 15 | 19 | | | C |
| September | 18 | 15 | 21 | | | C |
| October | 14 | 13 | 15 | | B | |
| November | 10.33 | 8 | 12 | | B | |
| December | 8.5 | 7 | 10 | | B | |

The occurrence of no significant, long-term trends in the constituents monitored indicates that conditions are stable. While water quality is not improving, it appears that the control measures implemented with recent mining operations are adequate to prevent further degradation of the water body.

# 3. SOURCE ASSESSMENT

The TMDL development described in this report included examination of all potential sources of identified stressors in the Black Creek Watershed. The source assessment was used as the basis of model development and ultimate analysis of TMDL allocation options. In evaluation of the sources, loads were characterized by the best available information, literature values, and measured data. This section documents the available information and interpretation for the analysis. The source assessment chapter is organized into point and nonpoint sections, point sources being those sources that can be spatially defined as having a single point of entry and a direct path to the stream and nonpoint sources being diffuse, hydrologically driven pollution sources. The representation of the following sources in the model is discussed in Section 4.

## *3.1 Assessment of Point Sources*

In watersheds with resource extraction activities, establishment and removal of permitted point sources is a dynamic process. At the onset of this study, there were nine point sources (Table C.1, Appendix C) permitted to discharge into Black Creek through the National Pollutant Discharge Elimination System (NPDES). With one exception, each of these point sources (Figure 3.1) is an outlet from a pond associated with mining activities. However, only two of these ponds were in place during the modeled period (Section 4.3.1). The single exception to the point sources being pond outlets is one of the two NPDES discharges associated with Mine Permit Number 1201542. This discharge is drainage from a deep mine. Summaries of monitoring conducted to support permit compliance efforts (Table 3.1 through 3.9) show that the levels of stressors in the permitted discharges are typically less than those measured in the stream (Section 2.3).

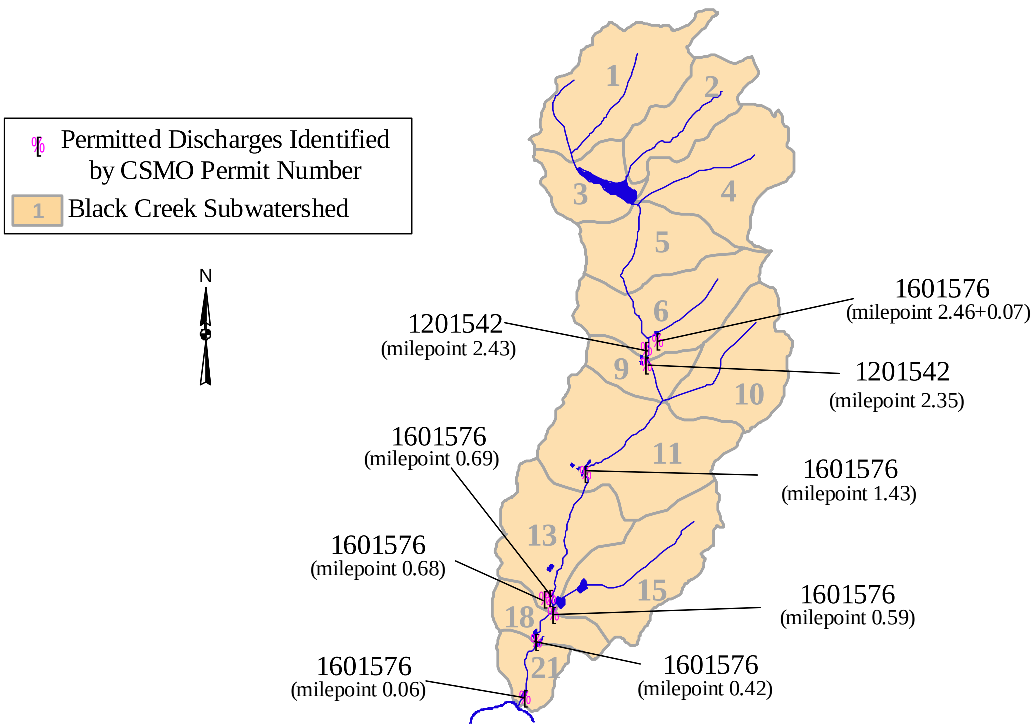


**Figure 3.1 Location of NPDES permitted point sources in the Black Creek Watershed**

**Table 3.1 Monitoring Data for Permitted Point Source at Milepoint 0.06 (Sampled 11/97-12/98)**

| Mile 0.06 | Mean | Median | Max | Min | SD[1] | N[2] |
|---|---|---|---|---|---|---|
| FLOW (gpm) | 49.93 | 45 | 150 | 2 | 32.97 | 28 |
| pH | 7.54 | 7.6 | 8 | 6.9 | 0.33 | 28 |
| Fe (mg/L) | 0.38 | 0.3 | 1.4 | 0.1 | 0.39 | 13 |
| Mn (mg/L) | 0.48 | 0.4 | 2 | 0.1 | 0.55 | 13 |
| TSS (mg/L) | 6.46 | 6 | 15 | 1 | 4.33 | 13 |

[1]SD: standard deviation, [2]N: number of sample measurements

**Table 3.2 Monitoring Data for Permitted Point Source at Milepoint 0.42 (Sampled 1/95-3/99)**

| Mile 0.42 | Mean | Median | Max | Min | SD[1] | N[2] |
|---|---|---|---|---|---|---|
| FLOW (gpm) | 34.39 | 25 | 300 | 1 | 45.82 | 66 |
| pH | 7.34 | 7.4 | 8.2 | 6.4 | 0.34 | 66 |
| Fe (mg/L) | 0.56 | 0.4 | 2 | 0.1 | 0.50 | 28 |
| Mn (mg/L) | 0.48 | 0.3 | 1.6 | 0.1 | 0.44 | 28 |
| TSS (mg/L) | 6.25 | 5 | 32 | 1 | 5.65 | 28 |

[1]SD: standard deviation, [2]N: number of sample measurements

**Table 3.3 Monitoring Data for Permitted Point Source at Milepoint 0.59 (Sampled 12/96-3/99)**

| Mile 0.59 | Mean | Median | Max | Min | SD[1] | N[2] |
|---|---|---|---|---|---|---|
| FLOW (gpm) | 54.96 | 27.5 | 350 | 1 | 62.22 | 46 |
| pH | 7.15 | 7.1 | 8 | 6.5 | 0.35 | 46 |
| Fe (mg/L) | 0.44 | 0.15 | 2.5 | 0.1 | 0.61 | 18 |
| Mn (mg/L) | 0.23 | 0.15 | 0.9 | 0.1 | 0.21 | 18 |
| TSS (mg/L) | 7.11 | 3.5 | 28 | 1 | 7.62 | 18 |

[1]SD: standard deviation, [2]N: number of sample measurements

**Table 3.4 Monitoring Data for Permitted Point Source at Milepoint 0.68 (Sampled 5/96-3/99)**

| Mile 0.68 | Mean | Median | Max | Min | SD[1] | N[2] |
|---|---|---|---|---|---|---|
| FLOW (gpm) | 27.11 | 20 | 200 | 2 | 31.43 | 45 |
| pH | 7.19 | 7.2 | 8 | 4.3 | 0.55 | 45 |
| Fe (mg/L) | 0.50 | 0.3 | 1.2 | 0.1 | 0.43 | 15 |
| Mn (mg/L) | 0.45 | 0.2 | 1.8 | 0.1 | 0.53 | 15 |
| TSS (mg/L) | 5.07 | 4 | 14 | 1 | 3.71 | 15 |

[1]SD: standard deviation, [2]N: number of sample measurements

**Table 3.5 Monitoring Data for Permitted Point Source at Milepoint 0.69 (Sampled 4/97-3/99)**

| Mile 0.69 | Mean | Median | Max | Min | SD[1] | N[2] |
|---|---|---|---|---|---|---|
| FLOW (gpm) | 104.68 | 100 | 500 | 5 | 75.22 | 47 |
| pH | 7.08 | 7 | 8 | 6.5 | 0.33 | 47 |
| Fe (mg/L) | 0.38 | 0.1 | 1.5 | 0.1 | 0.47 | 21 |
| Mn (mg/L) | 0.25 | 0.2 | 0.6 | 0.1 | 0.17 | 21 |
| TSS (mg/L) | 6.14 | 6 | 17 | 1 | 3.31 | 21 |

[1]SD: standard deviation, [2]N: number of sample measurements

**Table 3.6 Monitoring Data for Permitted Point Source at Milepoint 1.43 (Sampled 1/95-3/99)**

| Mile 1.43 | Mean | Median | Max | Min | SD[1] | N[2] |
|---|---|---|---|---|---|---|
| FLOW (gpm) | 50.49 | 45 | 180 | 3 | 37.93 | 86 |
| pH | 7.32 | 7.3 | 8.5 | 6.3 | 0.37 | 84 |
| Fe (mg/L) | 0.74 | 0.6 | 1.9 | 0.1 | 0.58 | 46 |
| Mn (mg/L) | 0.70 | 0.5 | 1.9 | 0.1 | 0.57 | 46 |
| TSS (mg/L) | 4.89 | 4.5 | 18 | 1 | 3.03 | 46 |

[1]SD: standard deviation, [2]N: number of sample measurements

**Table 3.7 Monitoring Data for Permitted Point Source at Milepoint 2.35 (Sampled 2/98-6/99)**

| Mile 2.35 | Mean | Median | Max | Min | SD[1] | N[2] |
|---|---|---|---|---|---|---|
| FLOW (gpm) | 58.15 | 50 | 250 | 0 | 55.74 | 34 |
| pH | 7.96 | 7.95 | 8.6 | 7.2 | 0.28 | 34 |
| Fe (mg/L) | 0.34 | 0.3 | 0.7 | 0.1 | 0.17 | 22 |
| Mn (mg/L) | 0.22 | 0.1 | 0.9 | 0 | 0.27 | 22 |
| TSS (mg/L) | 9.06 | 9 | 15 | 1 | 4.28 | 17 |

[1]SD: standard deviation, [2]N: number of sample measurements

**Table 3.8 Monitoring Data for Permitted Point Source at Milepoint 2.43 (Sampled 2/98-6/99)**

| Mile 2.43 | Mean | Median | Max | Min | SD[1] | N[2] |
|---|---|---|---|---|---|---|
| FLOW (gpm) | 57.40 | 50 | 250 | 0 | 58.77 | 30 |
| pH | 7.99 | 8 | 8.6 | 7.2 | 0.28 | 30 |
| Fe (mg/L) | 0.34 | 0.3 | 0.7 | 0.1 | 0.18 | 19 |
| Mn (mg/L) | 0.22 | 0.1 | 0.9 | 0 | 0.29 | 19 |
| TSS (mg/L) | 9.13 | 9.5 | 15 | 1 | 4.41 | 16 |

[1]SD: standard deviation, [2]N: number of sample measurements

**Table 3.9 Monitoring Data for Permitted Point Source at Milepoint 2.46+0.07 (Sampled 2/99-5/99)**

| Mile 2.46+0.07 | Mean | Median | Max | Min | SD[1] | N[2] |
|---|---|---|---|---|---|---|
| FLOW (gpm) | 21.94 | 23 | 36 | 0.4 | 12.45 | 10 |
| pH | 5.01 | 4.85 | 7 | 4 | 0.79 | 10 |
| Fe (mg/L) | 0.52 | 0.3 | 1.6 | 0 | 0.57 | 9 |
| Mn (mg/L) | 2.16 | 1.6 | 4.8 | 0.1 | 1.79 | 9 |
| TSS (mg/L) | 13.33 | 11 | 31 | 6 | 9.14 | 6 |

[1]SD: standard deviation, [2]N: number of sample measurements

## *3.2 Assessment of Nonpoint Sources*

In the Black Creek Watershed, nonpoint sources of stressors during the modeled period included Acid Mine Drainage (AMD) and drainage from Abandoned Mine Lands (AML). These terms are somewhat interchangeable, however, in the context of this report, AMD will refer to drainage that has been identified as seeping to the surface of the land and being delivered to the stream, and drainage from AML will refer to any drainage that eventually makes its way to the stream, whether through groundwater, interflow, or surface runoff. Each of these sources has the potential to deliver significant loads of the stressors identified as being significant limiters of benthic health. Figure 3.2 shows the locations where data were collected on these types of sources, including mine seeps and groundwater wells.

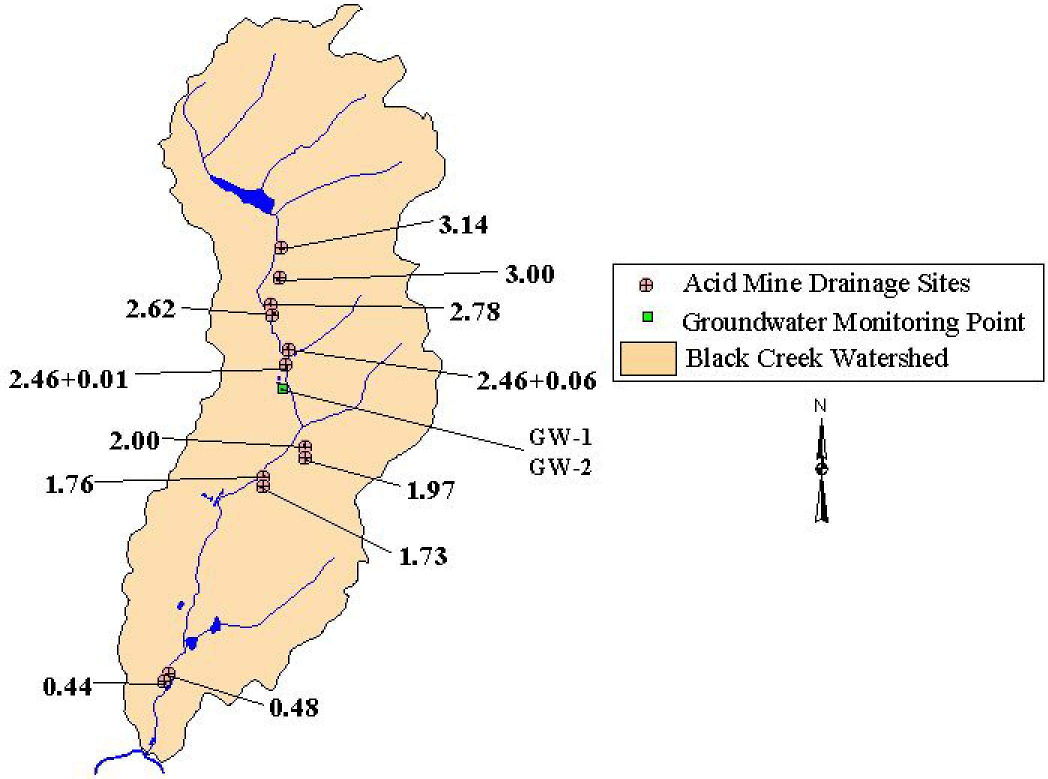


**Figure 3.2 Monitoring of Nonpoint Sources in the Black Creek Watershed**

### 3.2.1 Acid Mine Drainage (Mine Seeps)

D.R. Allen & Associates, P.C. compiled data available on mine seeps in the Black Creek Watershed for a pre-TMDL study. Twenty mine seeps were reported, 9 of which were identified in Professor Cherry's report. Of the 20 seeps reported by D.R. Allen, only 12 had a significant amount of monitored data reporting delivery of pollutants to the stream (Figure 3.2). Tables 3.10 through 3.21 summarize the data collected from these seeps. The seeps are typically characterized by low pH, high acidity, low alkalinity, high specific conductivity, and high concentrations of iron, manganese, total dissolved solids, and sulfate, relative to stream waters. Data in the summary tables include standard summary statistics (i.e. mean, median, maximum, minimum, standard deviation, and sample size), as well as, the estimated Seasonal-Kendall slope, where there is a significant trend.

**Table 3.10 Mine Discharge Data at Milepoint 0.44 (Sampled 1/96-3/99)**

| Mile 0.44 | Mean | Median | Max | Min | SD[1] | N[2] | Significant Trend[3] |
|---|---|---|---|---|---|---|---|
| FLOW (gpm) | 4.10 | 4 | 15 | 1 | 3.22 | 61 | -1.00 |
| pH | 7.42 | 7.4 | 8.6 | 7 | 0.33 | 61 | No Trend |
| Fe (mg/L) | 0.53 | 0.21 | 2.8 | 0.04 | 0.76 | 13 | -- |
| Mn (mg/L) | 0.15 | 0.1 | 0.4 | 0.02 | 0.11 | 13 | -- |
| TSS (mg/L) | 9.69 | 6 | 26 | 1 | 8.88 | 13 | -- |
| ACIDITY (mg/L) | 0 | 0 | 0 | 0 | 0 | 13 | -- |
| ALKALINITY (mg/L) | 95.85 | 83 | 181 | 34 | 46.61 | 13 | -- |
| CONDUCTIVITY (µmhos/cm) | 871.48 | 710 | 1,900 | 320 | 400.61 | 61 | No Trend |
| TDS (mg/L) | 556.15 | 612 | 1,000 | 174 | 267.42 | 13 | -- |
| SULFATE (mg/L) | 273.08 | 210 | 560 | 150 | 129.17 | 13 | -- |
| HARDNESS | 352.60 | 341 | 808 | 84 | 201.00 | 10 | -- |
| CHLORIDE | 17.60 | 17 | 47 | 5 | 12.33 | 10 | -- |

[1]SD: standard deviation, [2]N: number of sample measurements, [3]A number in the significant trend column represents the Seasonal-Kendall estimated slope, "—" insufficient data

**Table 3.11 Mine Discharge Data at Milepoint 0.48 (Sampled 2/96-3/99)**

| Mile 0.48 | Mean | Median | Max | Min | SD[1] | N[2] | Significant Trend[3] |
|---|---|---|---|---|---|---|---|
| FLOW (gpm) | 4.15 | 4 | 15 | 1 | 3.44 | 60 | -2.00 |
| pH | 7.41 | 7.4 | 8.1 | 7 | 0.34 | 60 | No Trend |
| Fe (mg/L) | 0.34 | 0.1 | 2 | 0.02 | 0.57 | 12 | -- |
| Mn (mg/L) | 0.19 | 0.1 | 0.5 | 0.02 | 0.14 | 12 | -- |
| TSS (mg/L) | 10.17 | 7 | 40 | 1 | 11.44 | 12 | -- |
| ACIDITY (mg/L) | 0 | 0 | 0 | 0 | 0 | 12 | -- |
| ALKALINITY (mg/L) | 124.25 | 111 | 296 | 46 | 68.18 | 12 | -- |
| CONDUCTIVITY (µmhos/cm) | 1,306.33 | 1,500 | 2,300 | 180 | 523.82 | 60 | No Trend |
| TDS (mg/L) | 841.83 | 796 | 1,750 | 142 | 500.36 | 12 | -- |
| SULFATE (mg/L) | 338.33 | 390 | 560 | 125 | 157.86 | 12 | -- |
| HARDNESS | 610.00 | 594 | 1,213 | 157 | 345.33 | 10 | -- |
| CHLORIDE | 19.30 | 17 | 43 | 6 | 12.89 | 10 | -- |

[1]SD: standard deviation, [2]N: number of sample measurements, [3]A number in the significant trend column represents the Seasonal-Kendall estimated slope, "—" insufficient data

**Table 3.12 Mine Discharge Data at Milepoint 1.73 (Sampled 12/92-3/99)**

| Mile 1.73 | Mean | Median | Max | Min | SD[1] | N[2] | Significant Trend[3] |
|---|---|---|---|---|---|---|---|
| FLOW (gpm) | 76.33 | 60 | 1,000 | 10 | 103.94 | 94 | 15.00 |
| pH | 7.41 | 7.5 | 8.2 | 6.4 | 0.40 | 94 | No Trend |
| Fe (mg/L) | 1.20 | 0.1 | 16.1 | 0.02 | 3.73 | 48 | 0.036 |
| Mn (mg/L) | 0.23 | 0.1 | 1.3 | 0.02 | 0.28 | 48 | 0.02 |
| TSS (mg/L) | 44.75 | 9.5 | 1,080 | 1 | 171.05 | 48 | No Trend |
| ACIDITY (mg/L) | 0 | 0 | 0 | 0 | 0 | 48 | No Trend |
| ALKALINITY (mg/L) | 108.56 | 113 | 216 | 31 | 33.10 | 48 | No Trend |
| CONDUCTIVITY (μmhos/cm) | 1,414.68 | 1,500 | 2,300 | 100 | 411.21 | 94 | No Trend |
| TDS (mg/L) | 973.63 | 1,014 | 1,560 | 180 | 324.98 | 48 | No Trend |
| SULFATE (mg/L) | 449.17 | 500 | 920 | 0.02 | 199.13 | 48 | No Trend |
| HARDNESS | 540.40 | 599.5 | 786 | 68 | 240.29 | 10 | -- |
| CHLORIDE | 17.40 | 16 | 45 | 4 | 12.32 | 10 | -- |

[1]SD: standard deviation, [2]N: number of sample measurements, [3]A number in the significant trend column represents the Seasonal-Kendall estimated slope, "—" insufficient data

**Table 3.13 Mine Discharge Data at Milepoint 1.76 (Sampled 12/92-3/99)**

| Mile 1.76 | Mean | Median | Max | Min | SD[1] | N[2] | Significant Trend[3] |
|---|---|---|---|---|---|---|---|
| FLOW (gpm) | 24.84 | 20 | 105 | 4 | 17.04 | 77 | 3.50 |
| pH | 7.01 | 7 | 8 | 6.3 | 0.30 | 78 | No Trend |
| Fe (mg/L) | 0.15 | 0.04 | 0.7 | 0.02 | 0.20 | 29 | -- |
| Mn (mg/L) | 0.18 | 0.1 | 0.8 | 0.02 | 0.21 | 29 | -- |
| TSS (mg/L) | 7.07 | 5 | 22 | 1 | 6.37 | 29 | -- |
| ACIDITY (mg/L) | 0 | 0 | 0 | 0 | 0 | 29 | -- |
| ALKALINITY (mg/L) | 69.86 | 42 | 191 | 24 | 47.57 | 29 | -- |
| CONDUCTIVITY (μmhos/cm) | 984.87 | 815 | 2,300 | 170 | 510.23 | 78 | No Trend |
| TDS (mg/L) | 796.93 | 769 | 2,035 | 168 | 384.96 | 29 | -- |
| SULFATE (mg/L) | 393.28 | 350 | 1,600 | 55 | 272.35 | 29 | -- |
| HARDNESS | 424.30 | 420.5 | 744 | 216 | 153.24 | 10 | -- |
| CHLORIDE | 18.50 | 21.5 | 35 | 6 | 10.39 | 10 | -- |

[1]SD: standard deviation, [2]N: number of sample measurements, [3]A number in the significant trend column represents the Seasonal-Kendall estimated slope, "—" insufficient data

**Table 3.14 Mine Discharge Data at Milepoint 1.97 (Sampled 12/92-6/98)**

| Mile 1.97 | Mean | Median | Max | Min | SD[1] | N[2] | Significant Trend[3] |
|---|---|---|---|---|---|---|---|
| FLOW (gpm) | 2.16 | 2 | 8 | 0.5 | 1.89 | 19 | -- |
| pH | 7.22 | 7.1 | 8 | 6.5 | 0.37 | 19 | -- |
| Fe (mg/L) | 0.09 | 0.04 | 0.37 | 0.02 | 0.11 | 16 | -- |
| Mn (mg/L) | 0.04 | 0.02 | 0.12 | 0.02 | 0.03 | 16 | -- |
| TSS (mg/L) | 9.63 | 8 | 40 | 1 | 10.49 | 16 | -- |
| ACIDITY (mg/L) | 0 | 0 | 0 | 0 | 0 | 16 | -- |
| ALKALINITY (mg/L) | 40.06 | 34 | 98 | 22 | 18.89 | 16 | -- |
| CONDUCTIVITY (µmhos/cm) | 523.95 | 490 | 1,100 | 310 | 197.64 | 19 | -- |
| TDS (mg/L) | 395.50 | 391 | 534 | 194 | 102.22 | 16 | -- |
| SULFATE (mg/L) | 203.19 | 210 | 340 | 20 | 84.36 | 16 | -- |
| HARDNESS | 180.00 | 180 | 180 | 180 | | 1 | -- |
| CHLORIDE | 19.00 | 19 | 19 | 19 | | 1 | -- |

[1]SD: standard deviation, [2]N: number of sample measurements, [3]A number in the significant trend column represents the Seasonal-Kendall estimated slope, "—" insufficient data

**Table 3.15 Mine Discharge Data at Milepoint 2.00 (Sampled 12/95-3/99)**

| Mile 2.00 | Mean | Median | Max | Min | SD[1] | N[2] | Significant Trend[3] |
|---|---|---|---|---|---|---|---|
| FLOW (gpm) | 29.16 | 35 | 85 | 2 | 17.69 | 63 | No Trend |
| pH | 7.29 | 7.3 | 7.8 | 6.1 | 0.34 | 63 | No Trend |
| Fe (mg/L) | 0.52 | 0.115 | 3.5 | 0.02 | 0.97 | 14 | -- |
| Mn (mg/L) | 0.11 | 0.1 | 0.4 | 0.02 | 0.10 | 14 | -- |
| TSS (mg/L) | 17.57 | 14 | 46 | 1 | 13.45 | 14 | -- |
| ACIDITY (mg/L) | 0 | 0 | 0 | 0 | 0 | 14 | -- |
| ALKALINITY (mg/L) | 68.00 | 57 | 130 | 39 | 28.30 | 14 | -- |
| CONDUCTIVITY (µmhos/cm) | 925.08 | 830 | 1,900 | 450 | 401.76 | 63 | No Trend |
| TDS (mg/L) | 689.43 | 693 | 1,028 | 264 | 209.06 | 14 | -- |
| SULFATE (mg/L) | 348.21 | 367.5 | 525 | 50 | 130.53 | 14 | -- |
| HARDNESS | 432.70 | 466 | 608 | 88 | 165.68 | 10 | -- |
| CHLORIDE | 17.90 | 18.5 | 42 | 4 | 10.45 | 10 | -- |

[1]SD: standard deviation, [2]N: number of sample measurements, [3]A number in the significant trend column represents the Seasonal-Kendall estimated slope, "—" insufficient data

**Table 3.16 Mine Discharge Data at Milepoint 2.46+0.01 (Sampled 12/92-11/98)**

| Mile 2.46+0.01 | Mean | Median | Max | Min | SD[1] | N[2] | Significant Trend[3] |
|---|---|---|---|---|---|---|---|
| FLOW (gpm) | 37.18 | 35.5 | 127 | 2 | 28.20 | 84 | -5.75 |
| pH | 5.14 | 5 | 7.2 | 3.1 | 1.08 | 83 | 0.358 |
| Fe (mg/L) | 0.61 | 0.39 | 3.46 | 0.02 | 0.70 | 43 | No Trend |
| Mn (mg/L) | 2.88 | 2.53 | 9.77 | 0.05 | 2.37 | 43 | -0.832 |
| TSS (mg/L) | 15.88 | 10 | 150 | 1 | 24.48 | 43 | No Trend |
| ACIDITY (mg/L) | 95.84 | 91 | 388 | 0 | 96.51 | 43 | No Trend |
| ALKALINITY (mg/L) | 13.19 | 0 | 95 | 0 | 25.54 | 43 | 0.6 |
| CONDUCTIVITY (µmhos/cm) | 1,786.69 | 1,800 | 3,000 | 145 | 429.20 | 83 | No Trend |
| TDS (mg/L) | 1,435.35 | 1,342 | 2,183 | 488 | 341.21 | 43 | No Trend |
| SULFATE (mg/L) | 669.74 | 575 | 2,900 | 54 | 450.86 | 43 | No Trend |
| HARDNESS | 768.44 | 860 | 1,027 | 136 | 293.06 | 9 | -- |
| CHLORIDE | 14.78 | 14 | 24 | 5 | 7.19 | 9 | -- |

[1]SD: standard deviation, [2]N: number of sample measurements, [3]A number in the significant trend column represents the Seasonal-Kendall estimated slope, "—" insufficient data

**Table 3.17 Mine Discharge Data at Milepoint 2.46+0.06 (Sampled 12/92-11/98)**

| Mile 2.46+0.06 | Mean | Median | Max | Min | SD[1] | N[2] | Significant Trend[3] |
|---|---|---|---|---|---|---|---|
| FLOW (gpm) | 47.93 | 36 | 162 | 6 | 38.65 | 84 | -15.00 |
| pH | 6.91 | 6.9 | 7.7 | 6.1 | 0.29 | 84 | -0.044 |
| Fe (mg/L) | 4.46 | 2.755 | 28.4 | 0.05 | 5.53 | 44 | No Trend |
| Mn (mg/L) | 1.89 | 2 | 4.1 | 0.03 | 1.16 | 44 | No Trend |
| TSS (mg/L) | 30.14 | 25.5 | 88 | 1 | 21.85 | 44 | No Trend |
| ACIDITY (mg/L) | 1.55 | 0 | 68 | 0 | 10.25 | 44 | No Trend |
| ALKALINITY (mg/L) | 139.00 | 143.5 | 231 | 0 | 37.77 | 44 | No Trend |
| CONDUCTIVITY (µmhos/cm) | 853.99 | 830 | 1,500 | 345 | 161.83 | 84 | No Trend |
| TDS (mg/L) | 621.55 | 579 | 1,538 | 360 | 186.23 | 44 | No Trend |
| SULFATE (mg/L) | 246.16 | 242.5 | 820 | 0 | 122.47 | 44 | No Trend |
| HARDNESS | 321.33 | 328 | 401 | 176 | 63.77 | 9 | -- |
| CHLORIDE | 13.56 | 13 | 22 | 4 | 6.29 | 9 | -- |

[1]SD: standard deviation, [2]N: number of sample measurements, [3]A number in the significant trend column represents the Seasonal-Kendall estimated slope, "—" insufficient data

**Table 3.18 Mine Discharge Data at Milepoint 2.62 (Sampled 12/92-3/99)**

| Mile 2.62 | Mean | Median | Max | Min | SD[1] | N[2] | Significant Trend[3] |
|---|---|---|---|---|---|---|---|
| FLOW (gpm) | 39.44 | 36 | 150 | 4 | 30.40 | 95 | -8.70 |
| pH | 4.01 | 4 | 7.2 | 2.8 | 0.65 | 95 | No Trend |
| Fe (mg/L) | 1.83 | 0.6 | 19.73 | 0.02 | 3.36 | 49 | No Trend |
| Mn (mg/L) | 1.82 | 1.7 | 5.04 | 0.04 | 1.22 | 49 | No Trend |
| TSS (mg/L) | 17.16 | 8 | 236 | 1 | 36.67 | 49 | No Trend |
| ACIDITY (mg/L) | 231.84 | 240 | 614 | 0 | 143.45 | 49 | No Trend |
| ALKALINITY (mg/L) | 6.22 | 0 | 198 | 0 | 31.21 | 49 | No Trend |
| CONDUCTIVITY (µmhos/cm) | 1,524.63 | 1,600 | 2,500 | 510 | 420.52 | 95 | No Trend |
| TDS (mg/L) | 1,096.00 | 1,003 | 1,908 | 461 | 329.57 | 49 | No Trend |
| SULFATE (mg/L) | 529.45 | 530 | 1,700 | 4.9 | 280.05 | 49 | No Trend |
| HARDNESS | 562.40 | 634 | 748 | 104 | 190.06 | 10 | -- |
| CHLORIDE | 15.30 | 15 | 24 | 5 | 6.77 | 10 | -- |

[1]SD: standard deviation, [2]N: number of sample measurements, [3]A number in the significant trend column represents the Seasonal-Kendall estimated slope, "—" insufficient data

**Table 3.19 Mine Discharge Data at Milepoint 2.78 (Sampled 12/92-3/99)**

| Mile 2.78 | Mean | Median | Max | Min | SD[1] | N[2] | Significant Trend[3] |
|---|---|---|---|---|---|---|---|
| FLOW (gpm) | 3.02 | 0.4 | 36 | 0.4 | 5.67 | 93 | No Trend |
| pH | 4.02 | 4.1 | 7.4 | 2.6 | 0.71 | 93 | No Trend |
| Fe (mg/L) | 2.95 | 0.6 | 11.64 | 0.02 | 3.63 | 47 | -1.12 |
| Mn (mg/L) | 3.86 | 2 | 10.96 | 0.02 | 3.54 | 47 | -1.277 |
| TSS (mg/L) | 10.15 | 4 | 98 | 1 | 17.15 | 47 | No Trend |
| ACIDITY (mg/L) | 204.34 | 209 | 857 | 0 | 144.08 | 47 | -21 |
| ALKALINITY (mg/L) | 3.64 | 0 | 147 | 0 | 21.44 | 47 | No Trend |
| CONDUCTIVITY (µmhos/cm) | 1,514.52 | 1,500 | 3,000 | 310 | 521.73 | 93 | No Trend |
| TDS (mg/L) | 1,046.17 | 1,018 | 2,892 | 582 | 371.70 | 47 | -93 |
| SULFATE (mg/L) | 546.32 | 525 | 1,400 | 62 | 250.10 | 47 | No Trend |
| HARDNESS | 473.70 | 507 | 611 | 176 | 126.43 | 10 | -- |
| CHLORIDE | 16.20 | 14.5 | 33 | 4 | 9.02 | 10 | -- |

[1]SD: standard deviation, [2]N: number of sample measurements, [3]A number in the significant trend column represents the Seasonal-Kendall estimated slope, "—" insufficient data

**Table 3.20 Mine Discharge Data at Milepoint 3.00 (Sampled 12/92-3/99)**

| Mile 3.00 | Mean | Median | Max | Min | SD[1] | N[2] | Significant Trend[3] |
|---|---|---|---|---|---|---|---|
| FLOW (gpm) | 63.47 | 25 | 481 | 0.58 | 78.94 | 94 | 6.667 |
| pH | 4.20 | 4.1 | 9.4 | 3.1 | 0.78 | 94 | No Trend |
| Fe (mg/L) | 0.75 | 0.38 | 9.1 | 0.023 | 1.38 | 48 | No Trend |
| Mn (mg/L) | 2.98 | 2.06 | 9.1 | 0.05 | 2.47 | 48 | -0.453 |
| TSS (mg/L) | 7.58 | 2 | 36 | 1 | 9.08 | 48 | No Trend |
| ACIDITY (mg/L) | 130.90 | 122 | 376 | 0 | 89.30 | 48 | 12.5 |
| ALKALINITY (mg/L) | 0.27 | 0 | 5 | 0 | 1.07 | 48 | No Trend |
| CONDUCTIVITY (µmhos/cm) | 1,301.76 | 1,300 | 3,000 | 400 | 457.21 | 94 | No Trend |
| TDS (mg/L) | 845.38 | 801.5 | 1,470 | 418 | 205.27 | 48 | No Trend |
| SULFATE (mg/L) | 440.83 | 450 | 950 | 70 | 153.62 | 48 | No Trend |
| HARDNESS | 475.00 | 508 | 625 | 184 | 126.40 | 10 | -- |
| CHLORIDE | 16.30 | 15.5 | 32 | 6 | 8.65 | 10 | -- |

[1]SD: standard deviation, [2]N: number of sample measurements, [3]A number in the significant trend column represents the Seasonal-Kendall estimated slope, "—" insufficient data

**Table 3.21 Mine Discharge Data at Milepoint 3.14 (Sampled 12/92-3/99)**

| Mile 3.14 | Mean | Median | Max | Min | SD[1] | N[2] | Significant Trend[3] |
|---|---|---|---|---|---|---|---|
| FLOW (gpm) | 61.34 | 50 | 300 | 10 | 42.48 | 96 | -8.33 |
| pH | 4.33 | 4.35 | 7.3 | 3.3 | 0.73 | 96 | No Trend |
| Fe (mg/L) | 0.33 | 0.1 | 3.7 | 0.02 | 0.63 | 50 | 0.017 |
| Mn (mg/L) | 1.28 | 1.32 | 3.5 | 0.02 | 0.82 | 50 | -0.155 |
| TSS (mg/L) | 8.10 | 4 | 40 | 1 | 9.42 | 50 | No Trend |
| ACIDITY (mg/L) | 174.02 | 164 | 603 | 0 | 147.04 | 50 | 26.15 |
| ALKALINITY (mg/L) | 4.84 | 0 | 90 | 0 | 18.81 | 50 | No Trend |
| CONDUCTIVITY (µmhos/cm) | 1,585.57 | 1,700 | 3,000 | 180 | 474.04 | 96 | No Trend |
| TDS (mg/L) | 1,191.54 | 1,185.5 | 1,702 | 248 | 295.87 | 50 | No Trend |
| SULFATE (mg/L) | 582.70 | 550 | 2,950 | 65 | 423.79 | 50 | No Trend |
| HARDNESS | 655.40 | 688.5 | 808 | 136 | 192.89 | 10 | -- |
| CHLORIDE | 15.40 | 17 | 29 | 4 | 8.50 | 10 | -- |

[1]SD: standard deviation, [2]N: number of sample measurements, [3]A number in the significant trend column represents the Seasonal-Kendall estimated slope, "—" insufficient data

#### *3.2.1.1 Trend and Seasonal Analysis on Acid Mine Discharge Sources*

Data collected at mine seeps in the Black Creek Watershed were analyzed for significant trends and seasonal differences. Monthly averages of flow rates and stressor concentrations were calculated for each sampling month. Table 3.22 shows the milepoints and the time periods over which samples were collected and analyzed. Only 19 samples were collected over the time period at milepoint 1.97. Consequently, there was not enough data at this milepoint to conduct an analysis of long-term trend or seasonality.

**Table 3.22 Locations and Time Periods over which water samples were collected in Black Creek.**

| Milepoint | Sampling Time Period |
|---|---|
| 0.44 | January 1996 – March 1999 |
| 0.48 | February 1996 – March 1999 |
| 1.73 | December 1992 – March 1999 |
| 1.76 | December 1992 – March 1999 |
| 1.97 | December 1992 – June 1998 |
| 2.00 | December 1995 – March 1999 |
| 2.46+0.01 | December 1992 – November 1998 |
| 2.46+0.06 | December 1992 – November 1998 |
| 2.62 | December 1992 – March 1999 |
| 2.78 | December 1992 – March 1999 |
| 3.00 | December 1992 – March 1999 |
| 3.14 | December 1992 – March 1999 |

#### 3.2.1.1.1 pH

Monthly averages of pH measured in AMD draining to Black Creek were analyzed, and an overall, long-term trend was found at milepoints 2.46+0.01 and 2.46+0.06. The slope of the increase in mean monthly pH was estimated at 0.358 at milepoint 2.46+0.01. The p-value calculated for this test was 0.01, indicating a high level of significance. The slope of the decrease in mean monthly pH at milepoint 2.46+0.06 was estimated at –0.044 with a p-value of 0.03, indicating a high level of significance. At milepoint 3.14, no overall long-term trend was found, however a significant decreasing trend was estimated for February with a slope of –0.171 and a p-value of 0.04. No significant difference in monthly pH within years was detected.

#### 3.2.1.1.2 Iron

Monthly averages of iron concentrations measured in AMD draining to Black Creek were analyzed, and an overall, long-term trend was found at milepoints 1.73, 2.78, and 3.14. The slope of the increase in mean monthly iron was estimated at 0.036 mg/L/year at milepoint 1.73. The p-value calculated for this test was 0.001, indicating a high level of significance. At milepoint 2.78, a downward trend was detected from year to year. The slope of the decrease in mean monthly iron was estimated at –1.120 mg/L/year. The p-value calculated for the test at milepoint 2.78 was 0.004, indicating a high level of significance. At milepoint 2.78, for the month of December, a slope of –1.970 mg/L/year was estimated with a p-value of 0.02, indicating a high level of significance. The slope of the increase in mean monthly iron was estimated at 0.017 mg/L/year at milepoint 3.14. The p-value calculated for this test was 0.008 indicating a high level of significance. No significant difference in monthly iron concentrations within years was detected at any of the locations.

#### 3.2.1.1.3 Manganese

Monthly averages of manganese concentrations measured in AMD draining to Black Creek were analyzed, and a significant trend was found at milepoints 1.73, 2.46+0.01, 2.62, 2.78, 3.00, and 3.14. The slope of the increase in mean monthly manganese was estimated at 0.02 mg/L/year at milepoint 1.73. The p-value calculated for this test was 0.001, indicating a high level of significance. The slope of the decrease in mean monthly manganese at milepoint 2.46+0.01 was estimated at –0.832 mg/L/year, with a p-value of 0.001, indicating a high level of significance. At milepoints 2.62 and 2.78, a downward trend was detected from year to year. The slope of the decrease in mean monthly manganese was estimated at -0.295 and –1.277 mg/L/year, respectively. The p-values calculated for the tests at milepoints 2.62 and 2.78 were both 0.001, indicating a high level of significance. For the month of December, a slope of –0.430 mg/L/year was estimated at milepoint 2.62 and a slope of –1.946 mg/L/year was estimated at milepoint 2.72 with a p-value of 0.02 at each location, indicating a high level of significance. The slope of the decrease in mean monthly manganese concentrations was estimated at –0.453 mg/L/year at milepoint 3.00 and -0.155 mg/L/year at milepoint 3.14. The p-value calculated for this test was less than 0.001 at milepoint 3.00 and 0.009 at milepoint 3.14, indicating a high level of significance. No significant difference in monthly manganese concentrations within years was detected.

#### 3.2.1.1.4 TSS

Monthly averages of total suspended solids (TSS) measured in AMD draining to Black Creek were analyzed, and no overall, long-term trend was found at any location. No significant difference in monthly TSS within years was detected.

#### 3.2.1.1.5 Acidity

Mean monthly acidity measured in AMD draining to Black Creek was analyzed, and an overall, long-term trend in acidity was observed at milepoints 2.78, 3.00 and 3.14. The slope of the decrease in mean monthly acidity was estimated at –21.0 mg/L/year at milepoint 2.78. The p-value calculated at milepoint 2.78 was 0.01. At milepoints 3.00 and 3.14 there is an increasing trend in mean monthly acidity. The slope of the increase in mean monthly acidity was estimated at 12.50 and 26.15 mg/L/year, respectively for milepoints 3.00 and 3.14. The p-value calculated at milepoint 3.00 was 0.042 and the p-value calculated at milepoint 3.14 was 0.003. No significant difference in monthly acid concentrations within years was detected.

#### 3.2.1.1.6 Alkalinity

Mean monthly alkalinity measured in AMD draining to Black Creek was analyzed, and an overall, long-term increase in alkalinity was observed at milepoint 2.46+0.01. The slope of the increase in mean monthly alkalinity was estimated at 0.600 mg/L/year. The p-value calculated at milepoint 2.46+0.01 was 0.002. No significant difference in monthly alkaline concentrations within years was detected.

#### 3.2.1.1.7 Conductivity

Mean monthly conductivity measured in AMD draining to Black Creek was analyzed and no overall, long-term trend was found at any location. Differences in mean monthly conductivity at milepoint 2.62 are indicated in Table 3.23. Differences in mean monthly conductivity at milepoint 3.14 are indicated in Table 3.24. Conductivity in months with the same median group letter is not significantly different from each other. In general, conductivity in the summer-fall months tends to be higher than conductivity in the winter-spring months.

**Table 3.23 Summary of Moods Median Test on mean monthly conductivity at Black Creek, milepoint 2.62**

| Month | Mean (µmhos/cm) | Minimum (µmhos/cm) | Maximum (µmhos/cm) | Median Groups[1] | | |
|---|---|---|---|---|---|---|
| January | 1,315.3 | 1,000 | 1,500 | A | B | |
| February | 1,198.9 | 510 | 1,700 | A | B | |
| March | 1,363.9 | 810 | 1,800 | A | B | |
| April | 1,491.7 | 1,280 | 1,800 | A | B | |
| May | 1,068.9 | 590 | 1,750 | A | | |
| June | 1,518.9 | 1,373.3 | 2,500 | | B | |
| July | 1,944.4 | 1,600 | 2,200 | | B | C |
| August | 1,916.7 | 1,750 | 2,200 | | | C |
| September | 1,955.6 | 1,766.7 | 2,000 | | | C |
| October | 1,833.3 | 1,500 | 2,000 | | B | C |
| November | 1,599.2 | 840 | 1,933.3 | A | B | C |
| December | 1,373.1 | 800 | 1,833.3 | A | B | |

[1] Conductivity in months with the same median group letter is not significantly different from each other at the 95% level of significance.

**Table 3.24 Summary of Moods Median Test on mean monthly conductivity at Black Creek, milepoint 3.14**

| Month | Mean (µmhos/cm) | Minimum (µmhos/cm) | Maximum (µmhos/cm) | Median Groups[1] | |
|---|---|---|---|---|---|
| January | 874.6 | 1,000 | 1,650 | A | |
| February | 943.5 | 810 | 2,000 | A | B |
| March | 1,488.6 | 965 | 2,166.7 | A | B |
| April | 1,700 | 1,600 | 1,900 | A | B |
| May | 1,530.6 | 1,325 | 1,733.3 | A | |
| June | 1,486.7 | 1,126.7 | 1,800 | A | |
| July | 1,850 | 1,650 | 2,100 | | B |
| August | 1,883.3 | 1,800 | 2,000 | | B |
| September | 1,927.8 | 1,800 | 2,150 | | B |
| October | 2,033.3 | 1,850 | 2,400 | | B |
| November | 1,726.7 | 1,400 | 1,900 | A | B |
| December | 1,363.9 | 640 | 1,833.3 | A | |

[1]Conductivity in months with the same median group letter is not significantly different from each other at the 95% level of significance.

#### 3.2.1.1.8 TDS

Mean monthly total dissolved solids (TDS) concentrations measured in AMD draining to Black Creek were analyzed, and an overall, long-term decrease in TDS was observed at milepoint 2.78. The slope of the decrease in mean monthly TDS was estimated at –93.0 mg/L/year at milepoint 2.78. The p-value was less than 0.001, and there is a decreasing trend in mean monthly TDS for the month of December. The slope of the decrease in mean monthly TDS for December was estimated at –121.3 mg/L/year. The p-value calculated for this test was 0.008, indicating a high level of significance. No significant difference in monthly TDS concentrations within years was detected.

#### 3.2.1.1.9 Sulfate

Monthly averages of sulfate concentrations measured in AMD draining to Black Creek were analyzed, and no overall, long-term trend was found at any location. No significant difference in monthly sulfate within years was detected.

#### 3.2.1.1.10 Flow

Monthly averages of flow rate measured in AMD draining to Black Creek were analyzed, and an overall long-term year to year trend was found at milepoint 0.44, 0.48, 1,73, 1.76, 2.46+0.01, 2.46+0.06, 2.62, 3.00 and 3.14. All flow rates used in this analysis were estimated and therefore confidence in the trends identified was less than the confidence in trends of the previously discussed analyses. The slope of the decrease in mean monthly flow at milepoints 0.44 and 0.48 was estimated at –1.00 and –2.00 gpm/year, respectively. The p-values calculated for the tests were 0.05 and 0.006, respectively, indicating a high level of significance. An overall increasing trend was detected at milepoints 1.73 and 1.76. The increasing slopes were estimated at 15.00 and 3.50 gpm/year, respectively. The p-values calculated at milepoints 1.73 and 1.76 are less than 0.001 and 0.01, respectively. These p-values indicate a high level of significance. The significance in the trend at milepoint 1.73 may be largely due to an increasing year-to-year trend for the months of December, January, February and March. The slopes of the increasing trends for months December, January, February and March are 9.17,14.44, 18.33 and 33.33 gpm/year, respectively. The p-values calculated for the months of December, January, February and March are 0.01, 0.04, 0.04 and 0.02, respectively. The p-values calculated indicate a high level of significance. The significance in the trend at milepoint 1.76 may be largely due to an increasing trend for the month of February. The slope of the trend for February is 5.00 gpm/year, with a p-value of 0.02. The slope of the decrease in mean monthly flow at milepoint 2.46+0.01 and 2.46+0.06 was estimated at –5.75 and –15.0 gpm/year, respectively, with a p-value of 0.02 and less than 0.001, respectively, indicating a high level of significance. At milepoint 2.62, the slope of the decrease in mean monthly flow rate was estimated at –8.7 gpm/year. The p-value calculated for this test was 0.02, indicating a high level of significance. The slope of the increase in mean monthly flow rate was estimated at 6.67 gpm/year at milepoint 3.00. The p-value calculated for this test was less than 0.02, indicating a high level of significance. The slope of the decrease in mean monthly flow rate was estimated at –8.33 gpm/year at milepoint 3.14. The p-value calculated for this test was 0.02, indicating a high level of significance. No significant difference in monthly flow rate within years was detected.

#### 3.2.1.1.11 Summary of Trend Analyses on AMDs

No consistent trends were discovered in the AMD constituents. While some constituents in some seeps showed improvements, others showed degradation. In some cases, within individual seeps, some constituents showed improvement while others showed degradation. As was concluded with regard to stream water quality, the situation appears to be stable, with monitored operations neither degrading or improving AMD water quality.

### 3.2.2 Abandoned Mine Lands

In addition to impacts from AMD, abandoned mine lands (AML) have the potential to contribute to water quality problems through contributions in overland flow, interflow, and groundwater. Abandoned mine lands are areas impacted by surface mining, but not reclaimed to the standards of the 1977 Surface Mining Control and Reclamation Act (SMCRA). Land uses in these areas include: disturbed lands (areas disturbed by previous mining operations through removal of vegetation and/or grading), spoils (mine waste discarded in fills or piles), and benches (abandoned surface mine sites, which often leave exposed high walls).

All of these areas have the potential to deliver a higher level of suspended solids than that delivered from undisturbed areas in overland flow, due to removal of vegetation and disturbances of surface soil structure. The impact from un-reclaimed sites tends to be reduced over time, but where steep slopes are left bare, severe erosion can prevent revegetation and promote continued problems with erosion. Additionally, the acidity of soils at abandoned mine benches and spoils can be quite high. Professor Cherry's study found that eight of nine sites sampled in the Black Creek Watershed had pH values well below 7.0 (Table 3.25). Interflow and groundwater drainage from these areas may surface in the seeps discussed in the last section, or could be delivered directly to the stream. Whatever the delivery mechanism, this acid drainage will likely deliver the same constituents discussed in regard to mine seeps.

**Table 3.25 Values of pH in Soil Samples Taken from Black Creek Watershed on March 13, 1996, using Standard Measure**

| Site | pH |
|---|---|
| Highwall Southeast of Black Creek Lake | 4.23 |
| Spoils pile on way to UD-7 origin | 4.71 |
| Highwall above UD-1 | 5.55 |
| Spoils pile above UD-3 origin | 3.73 |
| UD-2 origin | 3.54 |
| Bench above UD-2 | 3.47 |
| UD-4 | 3.06 |
| UD-5 | 3.65 |
| UD-7 | 7.06 |
| Average | 4.333 |

### 3.2.3 Groundwater Data

The only significant groundwater data collected in the Black Creek Watershed, as reported by D.R. Allen, was at the single groundwater-monitoring site identified in Figure 3.2. At this site two wells were reported on, GW-1 and GW-2. Summary data from these two wells is presented in Tables 3.26 and 3.27. Data from these wells was collected from June 1996 to June 1999. The pH values measured in the shallower well, GW-2, were typically lower than those measured in the deeper well, however, sulfate and metal concentrations were typically greater in the deeper well.

**Table 3.26 Groundwater Data for Monitoring Station GW-1**

| GW-1 | Mean | Median | Max | Min | SD[1] | N[2] | Significant Trend[3] |
|---|---|---|---|---|---|---|---|
| Depth | 22.6 | 23.0 | 36.0 | 2.0 | 4.5 | 73 | n/a |
| PH | 7.48 | 7.60 | 8.10 | 6.50 | 0.34 | 73 | 0.200 |
| Fe (mg/L) | 3.59 | 1.40 | 18.80 | 0.30 | 5.49 | 13 | -- |
| Mn (mg/L) | 0.22 | 0.10 | 0.90 | 0.00 | 0.25 | 13 | -- |
| TSS (mg/L) | 16.5 | 11.0 | 84.0 | 4.0 | 21.1 | 13 | -- |
| ACIDITY (mg/L) | 10 | 10 | 10 | 10 | 0 | 3 | -- |
| ALKALINITY (mg/L) | 142.3 | 148.0 | 173.0 | 78.0 | 26.1 | 13 | -- |
| CONDUCTIVITY (μmhos/cm) | 443.1 | 422.0 | 688.0 | 159.0 | 108.6 | 73 | No Trend |
| TDS (mg/L) | 269.3 | 262.0 | 324.0 | 248.0 | 22.1 | 13 | -- |
| SULFATE (mg/L) | 68.8 | 63.0 | 133.0 | 40.0 | 28.7 | 13 | -- |
| CHLORIDE | 8.7 | 8.0 | 15.0 | 2.0 | 3.6 | 13 | -- |

[1]SD: standard deviation, [2]N: number of sample measurements, [3]A number in the significant trend column represents the Seasonal-Kendall estimated slope, "--" insufficient data, "n/a" not applicable

**Table 3.27 Groundwater Data for Monitoring Station GW-2**

| GW-2 | Mean | Median | Max | Min | SD[1] | N[2] | Significant Trend[3] |
|---|---|---|---|---|---|---|---|
| Depth | 6.2 | 6.0 | 10.0 | 3.0 | 1.3 | 61 | n/a |
| PH | 8.56 | 8.60 | 8.90 | 7.70 | 0.27 | 61 | 0.200 |
| Fe (mg/L) | 0.81 | 0.30 | 2.50 | 0.20 | 0.84 | 11 | -- |
| Mn (mg/L) | 0.05 | 0.00 | 0.40 | 0.00 | 0.12 | 11 | -- |
| TSS (mg/L) | 45.2 | 18.0 | 228.0 | 1.0 | 65.0 | 11 | -- |
| ACIDITY (mg/L) | 10 | 10 | 10 | 10 | 0 | 2 | -- |
| ALKALINITY (mg/L) | 292.4 | 321.0 | 339.0 | 126.0 | 68.3 | 11 | -- |
| CONDUCTIVITY (µmhos/cm) | 581.5 | 594.0 | 775.0 | 261.0 | 105.6 | 61 | -25.25 |
| TDS (mg/L) | 351.5 | 357.0 | 389.0 | 262.0 | 38.8 | 11 | -- |
| SULFATE (mg/L) | 19.0 | 12.0 | 66.0 | 6.0 | 17.9 | 11 | -- |
| CHLORIDE | 19.0 | 12.0 | 66.0 | 6.0 | 17.9 | 11 | -- |

[1]SD: standard deviation, [2]N: number of sample measurements, [3]A number in the significant trend column represents the Seasonal-Kendall estimated slope, "--" insufficient data, "n/a" not applicable

# 4. MODELING PROCEDURE: LINKING THE SOURCES TO THE ENDPOINT

Establishing the relationship between in-stream water quality and the source loadings is a critical component of TMDL development. It allows for the evaluation of management options that will achieve the desired water quality endpoint. In the development of a TMDL for the Black Creek Watershed, the relationship was defined through computer modeling based on data collected throughout the watershed. Monitored flow and water quality data were then used to verify that the relationships developed through modeling were accurate. In this section, the selection of modeling tools, parameter development, calibration, and model application are discussed.

## *4.1 Modeling Framework Selection*

As discussed in section 1.4, the USGS Hydrologic Simulation Program - Fortran (HSPF) water quality model and appropriate biometric models developed by MapTech were selected as the modeling framework to simulate existing conditions and to perform TMDL allocations. The HSPF model is a continuous simulation model that can account for NPS pollutants in runoff, as well as pollutants entering the flow channel from point sources. In establishing the existing and allocation conditions, seasonal variations in hydrology, climatic conditions, and watershed activities were explicitly accounted for in the model. The use of HSPF allowed consideration of seasonal aspects of precipitation patterns within the watershed.

The stream segment within each subwatershed is simulated as a single reach of open channel, referred to as a RCHRES. Water and pollutants from pervious and impervious land segments (PERLNDs and IMPLNDs) are transported to the RCHRES using mass links. Mass links are also used to connect the modeled RCHRES segments in the same configuration that real stream segments are found in the physical world. The same mass link principal is applied when water and pollutants are conveyed to a RCHRES via a point discharge, or water is withdrawn from a particular RCHRES.

To adequately represent the spatial variation in the watershed, the Black Creek drainage area was divided into 21 subwatersheds. The rationale for choosing these subwatersheds was based on the availability of water quality data, location of control structures, and the limitations of the HSPF model. Water quality data (e.g. pH, alkalinity, etc.) are available at specific locations throughout the watershed. Subwatershed outlets were chosen to coincide with these monitoring stations, since output from the model can only be obtained at the modeled subwatershed outlets. Additionally, subwatershed delineations were inserted at locations of control structures, including permitted point sources, so that discharge from these impoundments could be properly modeled, each as a unique RCHRES in the model. The structure of the model was developed such that control structures that were installed between 1996 and 1999 could be inserted as was deemed necessary by the modeling time period. With all possible control structures in the model, 21 subwatersheds were represented. For the modeling period chosen, 1991-1995 (Section 4.5), 15 subwatersheds are represented (Figure 4.1). Two of these subwatersheds (i.e. subwatersheds 12 and 19) represent permitted control structures, and are not represented graphically in Figure 4.1, but are represented in the model as draining approximately 70 acres from subwatersheds 11, 13, and 18. An implicit constraint in the HSPF model requires that the time of concentration in any subwatershed be greater than the time-step being used for the model. Given this modeling constraint and the desire to maintain a spatial distribution of watershed characteristics and associated parameters, a 3-minute modeling time-step was used. The spatial division of the watershed allowed for a more refined representation of pollutant sources, and a more realistic description of hydrologic factors in the watershed.

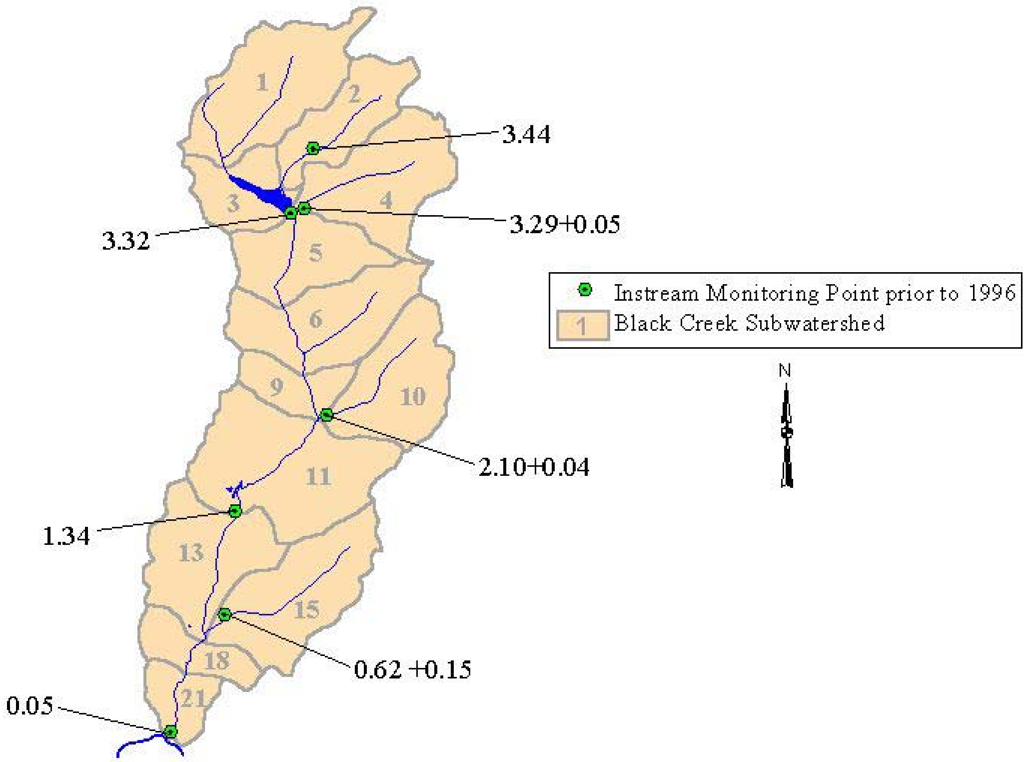


**Figure 4.1 Subwatersheds delineated for modeling and location of water quality monitoring stations in the Black Creek Watershed.**

Time-series output from HSPF was input into the biometric models developed to quantify end points (Appendix A). To be consistent with the original listing of Black Creek, the seven metrics used by Professor Cherry were modeled, and target stations were compared to the reference station (UBC-1) used by Cherry. One of the metrics, Community Loss Index, requires knowledge of the specific families that are present at the target and reference stations. Since this level of modeled output was not available, a pseudo Community Loss Index was calculated based on Taxa Richness at the target and reference stations as follows:

$$CLI = \frac{TR_{\text{Reference}} - TR_{\text{Target}}}{\text{Minimum}(TR_{\text{Reference}}, TR_{\text{Target}})}$$

where:

$CLI$ = Community Loss Index

$TR_{\text{Reference}}$ = Taxa Richness at the reference station

$TR_{\text{Target}}$ = Taxa Richness at the target station

The modeled biometrics were then used to calculate metric scores and a corresponding bioassessment.

## 4.2 Model Setup

Within each subwatershed, up to four land use types were represented. Model parameters were developed for each land use to describe the hydrology of the area (e.g. average slope length) and the behavior of pollutants (e.g. concentration of sulfate in groundwater). Table 4.1 shows the different land use types and the overall area of each in the Black Creek Watershed. These land use types are represented in HSPF as pervious land segments (PERLNDs). Some PERLND parameters (e.g. slope length) vary with the particular subwatershed in which they are located.

**Table 4.1 Spatial distribution of land use types in the Black Creek drainage area.**

| Land Use | Acreage |
|---|---|
| Benches | 40 |
| Spoils | 376 |
| Disturbed | 1,304 |
| Forest | 567 |

## 4.3 Source Representation

Both point and nonpoint sources can be represented in the model. For Black Creek, the only permitted point sources during the modeled period were discharges from control structures. These point sources were each modeled as a separate RCHRES, with appropriate characteristics to model the sediment trapping capacity of the structure. Nonpoint sources were modeled as having four potential delivery pathways, delivery with sediment in surface runoff, delivery through interflow, delivery through groundwater, and delivery through direct discharge of mine seeps to the stream. Pollutants associated with sediment were modeled as being delivered at a specific ratio to the amount of sediment. Pollutants associated with interflow and/or groundwater were modeled by assigning a constant concentration for each in a particular PERLND. Delivery through direct discharge by mine seeps is modeled by adding a time series of pollutant and flow inputs to the stream. Much of the data used to develop the model inputs for modeling water quality is time-dependent (e.g. existence of control structures). Depending on the timeframe of the simulation being run, the model was varied appropriately. The hydrologic landscape of the watershed was relatively stable during the modeled period (1991-1995). Data representing this period were used to develop the model used in this study.

## 4.3.1 Point Sources

### *4.3.1.1 Permitted Point Discharges*

Two permitted point discharges were present in the watershed during the modeled period (Figure 4.2). Both of these point sources were mine pond discharges associated with mine permit numbers 1201117 and 1601576. The first discharge located at milepoint 1.43 in subwatershed 11, included two ponds with Pond 1A, draining into Pond 1. Together, the ponds drained a total of approximately 2 acres of abandoned mine benches, 7 acres of spoils, 61 acres of disturbed land, and 0.3 acres of forest. This discharge was originally permitted under CSMO permit number 1201117, and transferred to permit number 1601576 in 1996. The second discharge, Pond 2, located at milepoint 0.42, was a single pond that drained approximately 1.5 acres of disturbed land and was established under CSMO permit number 1601576. While no water quality or flow data was available for calibrating modeled discharges from these structures, design data was available and was used for parameterizing the hydraulic response of the structure. As such, minimum volumes of runoff in the ponds were required before discharge would occur. Evaporation from the ponds was dependent on surface area, which varied with depth. Pollutant loadings from the modeled ponds were dependent on the land use areas draining to the pond and the residence time in the pond.

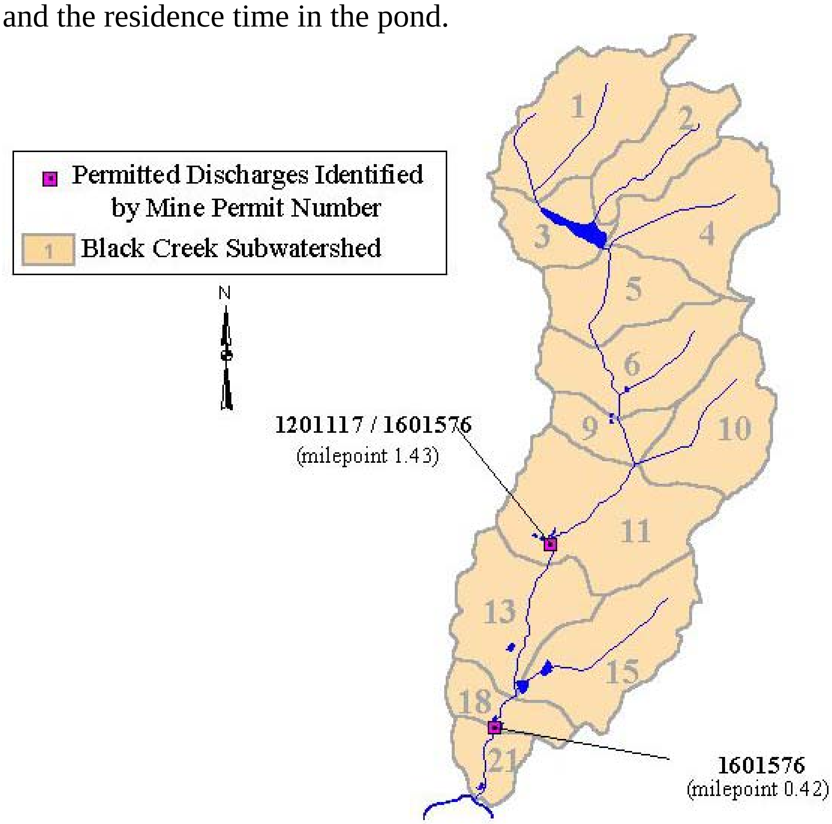


**Figure 4.2 Permitted point sources, operational during the modeled period.**

### *4.3.1.2 Non-Permitted Point Discharges*

Twelve mine seeps with significant monitored data were modeled as point discharges (Figure 4.3). This data included estimated flow, as well as concentrations of various water quality constituents (Section 3.2.1). The inclusion of these mine seeps as point discharges required the development of a flow time series representative of the observed data points (estimated). Analysis of the mine seep data to support model representation included a visual analysis to assess concentration dependence on flow volumes and a comparison of flow to precipitation data to evaluate mine seep response to rainfall events.

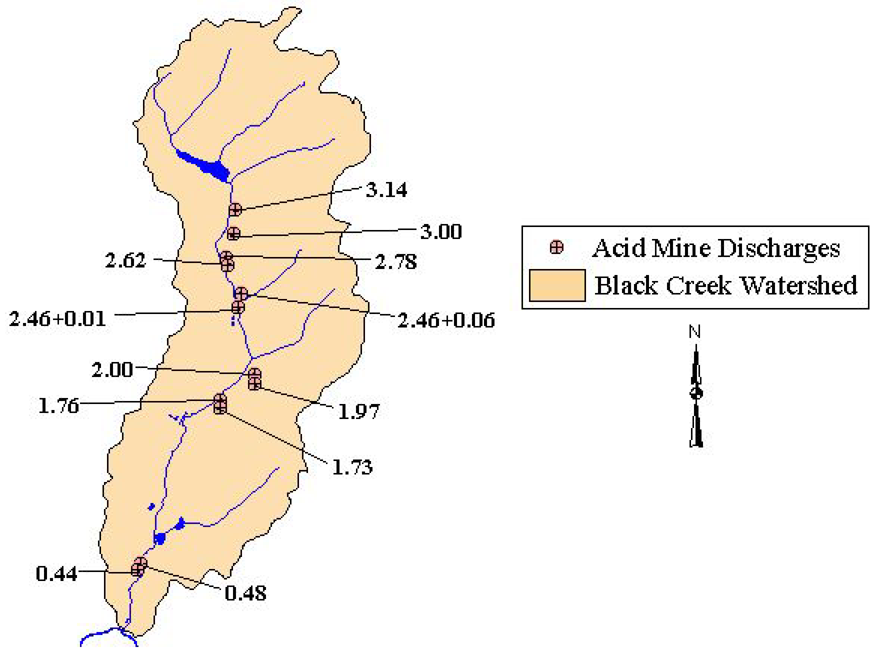


**Figure 4.3 Acid Mine Discharges in the Black Creek Watershed.**

Because flow values were all estimated, the use of monitored flow in any numerical analysis seemed questionable. To evaluate pollutant response to flow, all flows were divided into categories of “high” and “low” flow. Pollutant concentrations for each milepoint were then plotted and labeled as occurring during periods of high or low flow (Figure 4.4). These plots were then visually analyzed, resulting in the conclusion that pollutant concentrations were not particularly dependent on flow.

An analysis of flow data collected at the AMD sites in comparison to measured daily precipitation showed a closer correlation with rainfall events occurring two to three days prior to the flow measurement than to rainfall events occurring on the same day. While there was insufficient data to do a thorough analysis of this relationship, these preliminary results suggested that the flows from the mine seeps were more closely related to groundwater flows than overland flows. The HSPF model was used to generate a time series of groundwater flow. Each value in this time series was adjusted by a constant coefficient until the squared error was minimized between the resulting time series and observed values of flow at a particular mine seep. An example of a resulting flow time series is presented with observed values in figures 4.5. Patterns of increasing and decreasing flows fit well with the observed values.

These flows were then combined with measured values of the twelve pollutant concentrations to determine a set of time-series pollutant loadings from each AMD site. Since there was no obvious relationship between flow and concentration in the seep discharges, no effort was made to adjust concentrations with flow. Flow and pollutant loading were then incorporated in the model as time-series inputs, inserted into the appropriate subwatershed to represent the spatial distribution of seeps along the stream channels.

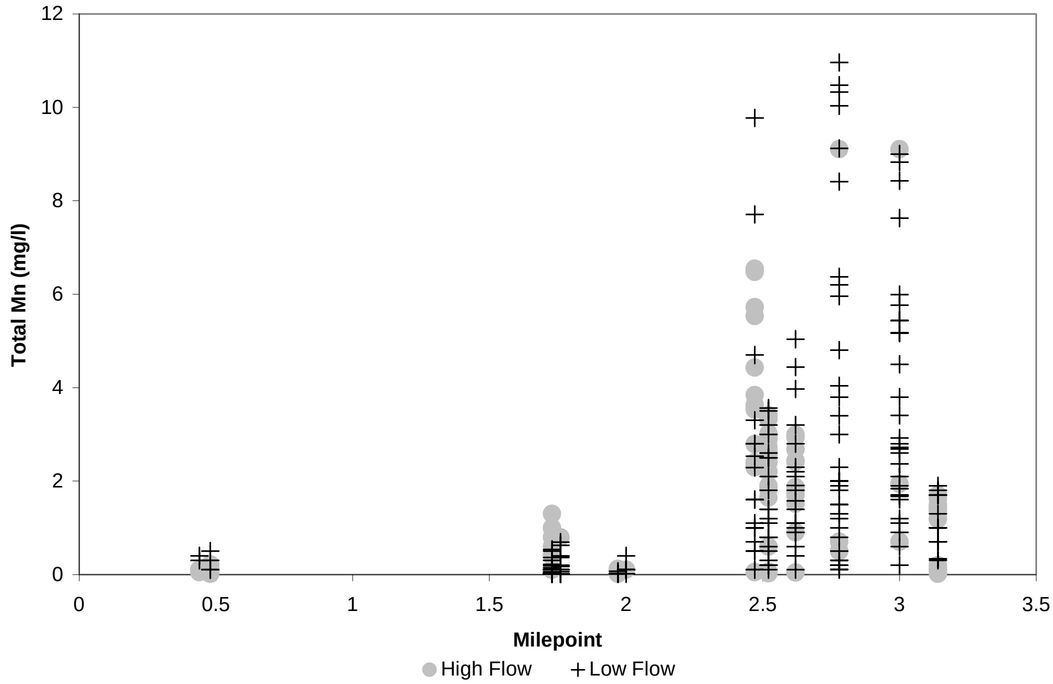


**Figure 4.4 Relationship between flow and concentration of Total Manganese at 12 mine seeps in the Black Creek Watershed.**

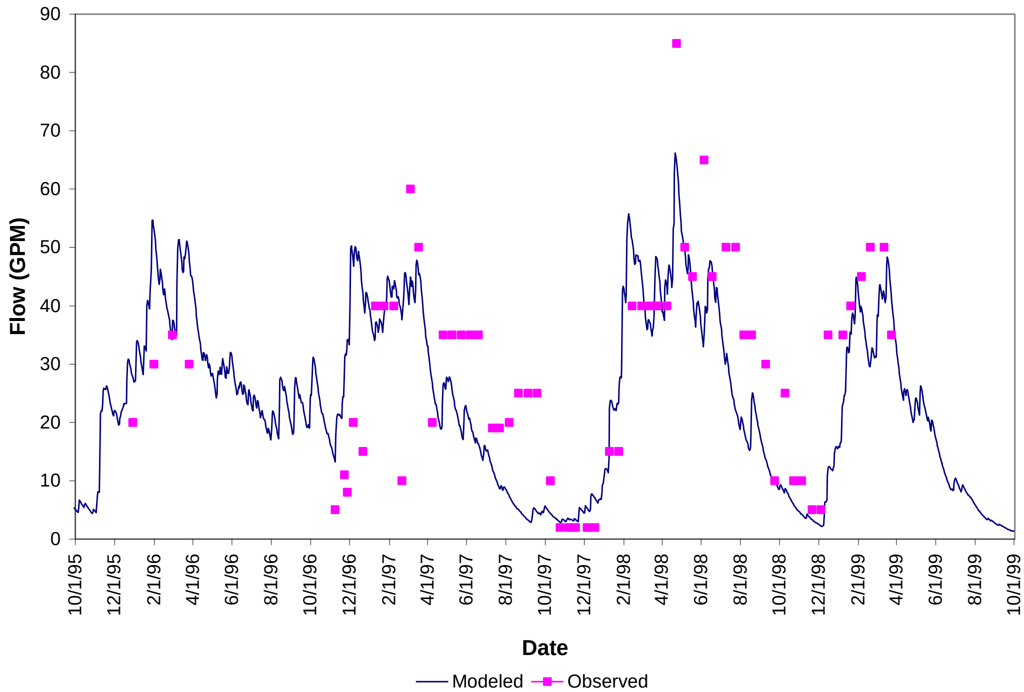


**Figure 4.5 Example of flow time series developed for input to the model (Milepoint 2.00).**

### 4.3.2 Nonpoint Sources

Nonpoint sources contributions from the four landuse categories (Table 4.1) were assumed to be delivered to the stream flow system in surface runoff, interflow and groundwater. Eight identified seeps (Figure 4.6 and Table 4.7) were included as nonpoint source contributions because insufficient monitored data was available for developing flow time series inputs.

The HSPF model was used to link pollutants from nonpoint sources with downstream water quality. The pollutants modeled included the benthic stressors identified in the multi-parameter statistical model discussed in Chapter 2. These included Total Dissolved Solids (TDS), Total Suspended Solids (TSS), Total and Dissolved Manganese (Mn), Total and Dissolved Iron (Fe), Sulfate, Specific Conductivity, Acidity, Alkalinity, and pH.

The pH algorithm within HSPF is based on the relationship between carbonate, alkalinity, and pH. When two of these factors are known the third can be calculated. The HSPF model incorporates a complex algorithm of the carbon cycle, including nutrient inputs that regulate phytoplankton growth, which controls growth and respiration of zooplankton. Alkalinity is modeled as a conservative constituent for input to the pH model. For this study, the concentration of total inorganic carbon was controlled through inputs from surface, interflow and groundwater runoff.

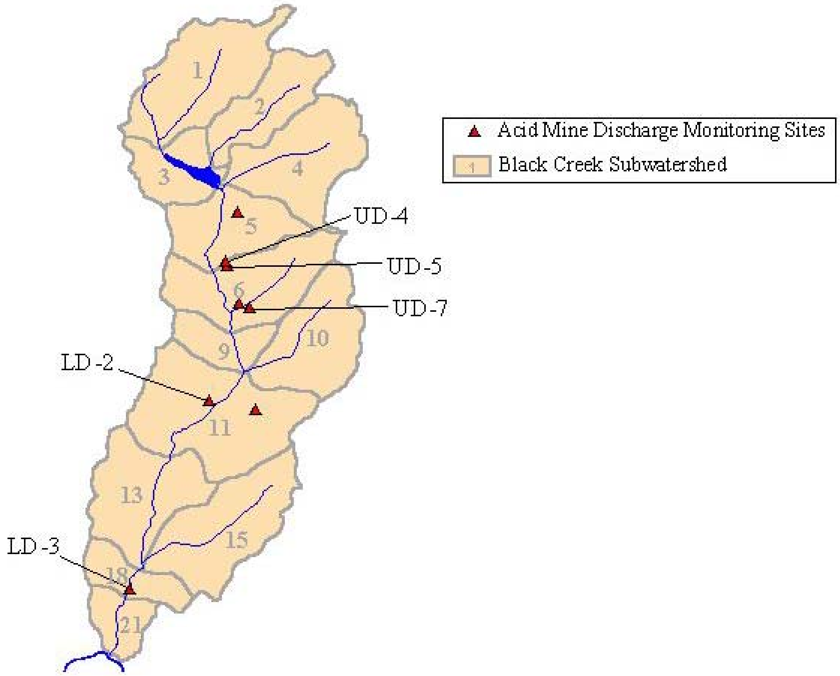


**Figure 4.6 Acid mine discharges identified in Black Creek with insufficient data for modeling as point sources.**

**Table 4.2 Location of acid mine discharges in the stream network modeled as point and nonpoint sources.**

| Subwatershed | # Acid Mine Discharges Point Sources | # Acid Mine Discharges Non Point Sources |
|---|---|---|
| 1 | 0 | 0 |
| 2 | 0 | 0 |
| 3 | 0 | 0 |
| 4 | 0 | 0 |
| 5 | 2 | 1 |
| 6 | 4 | 4 |
| 9 | 0 | 0 |
| 10 | 0 | 0 |
| 11 | 4 | 2 |
| 13 | 0 | 0 |
| 15 | 0 | 0 |
| 18 | 2 | 1 |
| 21 | 0 | 0 |
| **TOTAL** | **12** | **8** |

## *4.4 Stream Characteristics*

HSPF requires that each stream reach be represented by constant characteristics (e.g. stream geometry and resistance to flow). In order to determine a representative stream profile for each stream reach, cross-sections were surveyed at locations that were representative of the stream for the modeled subwatersheds (Figure 4.7). Where reaches varied widely, multiple cross-sections were measured and average values were used to describe the reach.

Most of the sections exhibited distinct flood plains with pitch and resistance to flow significantly different from that of the main channel slopes. The streambed, channel banks, and flood plains were identified. Once identified, the streambed width and slopes of channel banks and flood plains were calculated using the survey data. A representative stream profile for each surveyed cross-section was developed and consisted of a trapezoidal channel with pitch breaks at the beginning of the flood plain (Figure 4.8). With this approach, the flood plain can be represented differently from the streambed. To represent the entire reach, profile data collected at each end of the reach were averaged.

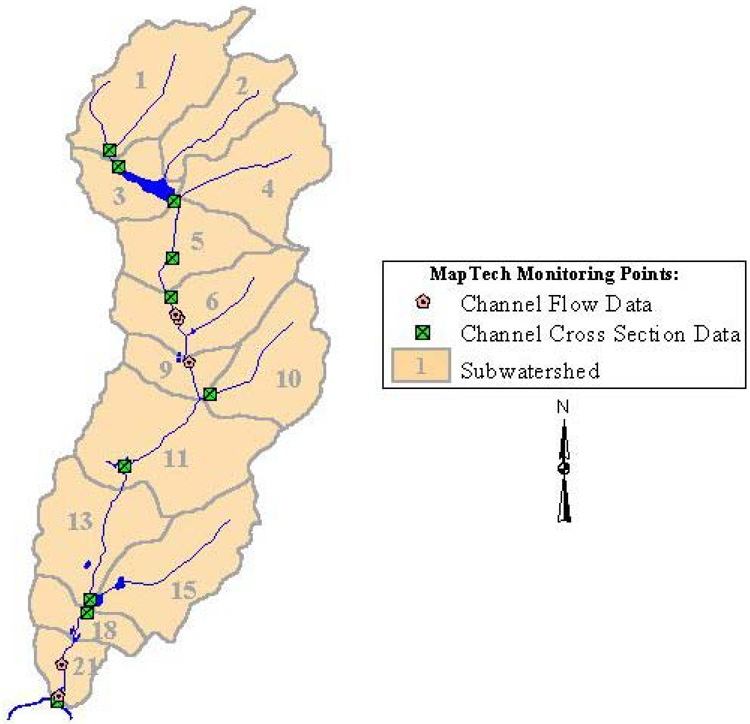


**Figure 4.7 Location of MapTech monitoring locations in Black Creek**

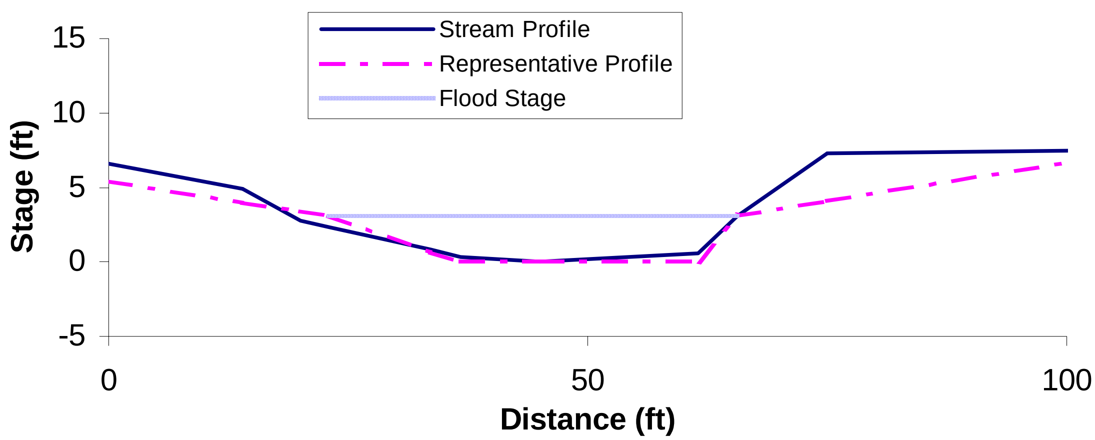


**Figure 4.8 Stream profile representation in HSPF.**

Conveyance was used to facilitate the calculation of discharge in the reach with different values for resistance to flow (i.e. Manning's n) assigned to the flood plains and streambeds. The conveyance was calculated for each of the two flood plains and the main channel, then added together to obtain a total conveyance. Calculation of conveyance was performed following the procedure described by Chow (1959). The total conveyance was then multiplied by the square root of the average reach slope to obtain the discharge (in $ft^3/s$) at a given depth.

A key parameter used in the calculation of conveyance is the Manning's roughness coefficient, n. There are many ways to estimate this parameter for a section. The method first introduced by Cowan (1956) and adopted by the Soil Conservation Service (1963) was used to estimate Manning's n. This procedure involves a 6-step process of evaluating the properties of the reach, which is explained in more detail by Chow (1959). Field data describing the channel bed, bank stability, vegetation, obstructions, and other pertinent parameters was collected. Photographs were also taken of the sections while in the field. Once the field data were collected, they were used to estimate the Manning's roughness coefficient for the section observed. The pictures were compared to pictures contained in Chow (1959) for validation of the estimates of the Manning's n for each section.

The result of the field inspections of the reach sections was a set of characteristic slopes (channel sides and field plains), bed widths, heights to flood plain, and Manning's roughness coefficients. Average reach slope and reach length were obtained from GIS layers of the watershed, which included elevation from Digital Elevation Models (DEMs) and a stream-flow network digitized from USGS 7.5-minute quadrangle maps (scale 1:24,000). These data were used to derive the Hydraulic Function Tables (F-tables) used by the HSPF model (Table 4.2). The F-tables developed consist of four columns; depth (ft), area (ac), volume (ac-ft), and outflow ($ft^3/s$). The depth represents the possible range of flow, with a maximum value beyond what would be expected for the reach. A maximum depth of 50 ft was used in the F-tables. The area listed is the surface area of the flow in acres. The volume corresponds to the total volume of the flow in the reach, and is reported in acre-feet. The outflow is simply the stream discharge, in cubic feet per second. The HSPF model calculates discharge based on volume of water in the reach. For the case of impoundments that were modeled in Black Creek, a minimum volume was set based on design parameters of the pond. During periods of no discharge from the pond, the only pathway for removal of water from the pond was evaporation.

**Table 4.3 Example of an "F-table" calculated for the HSPF Model.**

| DEPTH (FT) | AREA (ACRES) | VOLUME (AC-FT) | DISCH (CFS) |
|---|---|---|---|
| 0.0 | 0.5 | 0.0 | 0.0 |
| 0.2 | 0.7 | 0.1 | 4.5 |
| 0.4 | 0.8 | 0.3 | 15.4 |
| 0.6 | 0.9 | 0.4 | 32.5 |
| 0.8 | 1.0 | 0.6 | 56.2 |
| 1.0 | 1.1 | 0.8 | 86.9 |
| 1.3 | 1.3 | 1.2 | 147.7 |
| 1.7 | 1.4 | 1.7 | 255.4 |
| 2.0 | 1.5 | 2.2 | 344.6 |
| 2.3 | 1.6 | 2.7 | 438.1 |
| 2.7 | 1.7 | 3.3 | 569.1 |
| 3.0 | 1.7 | 3.8 | 672.3 |
| 6.0 | 2.2 | 9.5 | 2009.1 |
| 9.0 | 2.6 | 16.3 | 4158.1 |
| 12.0 | 2.8 | 23.2 | 6504.6 |
| 15.0 | 2.9 | 29.6 | 8402.2 |
| 25.0 | 2.9 | 50.2 | 14745.0 |

## 4.5 Selection of Representative Modeling Period

Selection of the modeling period was based on two factors; availability of data (discharge and water quality) and the need to represent critical hydrological conditions. Calibration is the process of comparing modeled data to observed data and making appropriate adjustments to model parameters to minimize the error between observed and simulated events. Using observed data that is reported at a shorter time-step improves this process and subsequently the performance of a time-dependent model. Validation is the process of comparing modeled data to observed data during a period of time other than that used for calibration. During validation, no adjustments are made to model parameters. The goal of validation is to assess the capability of the model in hydrologic conditions other than those used during calibration. In the case of Black Creek, data was sampled, at best, on a monthly basis and there are periods of time with no data available. Flow reported as part of the mine permit process was estimated. Through the public participation process, the quality of much of the data collected after June 1995 was called into question. Additionally, the output of the bioassessment model was to be assessed based on the benthic macroinvertebrate surveys conducted as part of Professor Cherry's study in August and October 1995. Due to these constraints, it was decided that none of the chemical/physical data collected after June 1995 would be used for calibration of the model. Additionally, since there was a limited amount of pre-1995 data, it was determined that the modeling effort would be more successful if all of these data were used for calibration, rather than dividing the dataset into smaller datasets for calibration and validation.

As reported in Section 2.2, assessment of aquatic health through the RBP reveals the impacts of stressors throughout a variety of hydrologic conditions, and a time period for calibration was chosen based on the overall distribution of wet and dry seasons. The mean daily precipitation for each season was calculated for the period October 1995 through September 2000. This resulted in 45 observations of precipitation for each season. The mean and variance of these observations were calculated. Next, a representative period for modeling was chosen and compared to the historical data. The initial period was chosen based on the availability of acceptable monitored data (12/31/92– 3/31/94). Additional years were added until the mean and variance of each season in the modeled time period was not significantly different from the historical data (Table 4.4). Therefore, the period was selected as representing the hydrologic regime of the study area, accounting for critical conditions associated with all potential sources within the watershed. The resulting time period for hydrologic calibration was October 1991 through September 1995.

**Table 4.4 Comparison of modeled time period to historical records.**

| | Precipitation (in/day) | | | |
|---|---|---|---|---|
| | Fall | Winter | Spring | Summer |
| | Historical Record (1955 - 2000) | | | |
| Mean | 10.8 | 13.2 | 13.6 | 13.6 |
| Variance | 8.0 | 15.6 | 11.7 | 13.6 |
| | Calibration Period (1/91 - 9/95) | | | |
| Mean | 11.1 | 14.4 | 13.3 | 12.1 |
| Variance | 9.5 | 7.2 | 3.6 | 6.5 |
| | P-Values | | | |
| Mean | 0.419 | 0.188 | 0.405 | 0.127 |
| Variance | 0.334 | 0.238 | 0.127 | 0.247 |

## *4.6 Model Calibration Process*

Calibration is performed in order to ensure that the model accurately represents the hydrologic and water quality processes in the watershed. The model's hydrologic parameters were set based on available soils, land use, and topographic data. Qualities of pollutant sources were modeled as described in chapters 3 and 4. Through calibration these parameters were adjusted within appropriate ranges until the model performance was deemed acceptable.

### 4.6.1 Hydrologic Calibration

Parameters that were adjusted during the hydrologic calibration represented the amount of evapotranspiration from the root zone (LZETP), the recession rates for groundwater (AGWRC) and interflow (IRC), the amount of soil moisture storage in the upper zone (UZSN) and lower zone (LZSN), the amount of interception storage (CEPSC), the infiltration capacity (INFILT), and the amount of soil water contributing to interflow (INTFW). A modeling start-up period (January 1991 - September 1991) was used to establish initial conditions.

Flow data was available at the outlet of subwatersheds 3, 4, 10, and 11 for the hydrologic calibration. Estimated flows were plotted against mean daily modeled flow values (Figures 4.9-4.22). The agreement between estimated and modeled flows was assessed, and adjustments to the model were made, as necessary, until an acceptable fit was achieved. Additionally, measured flow data, collected by MapTech as part of this study during particularly low flow conditions, were used to assess the minimum modeled flows.

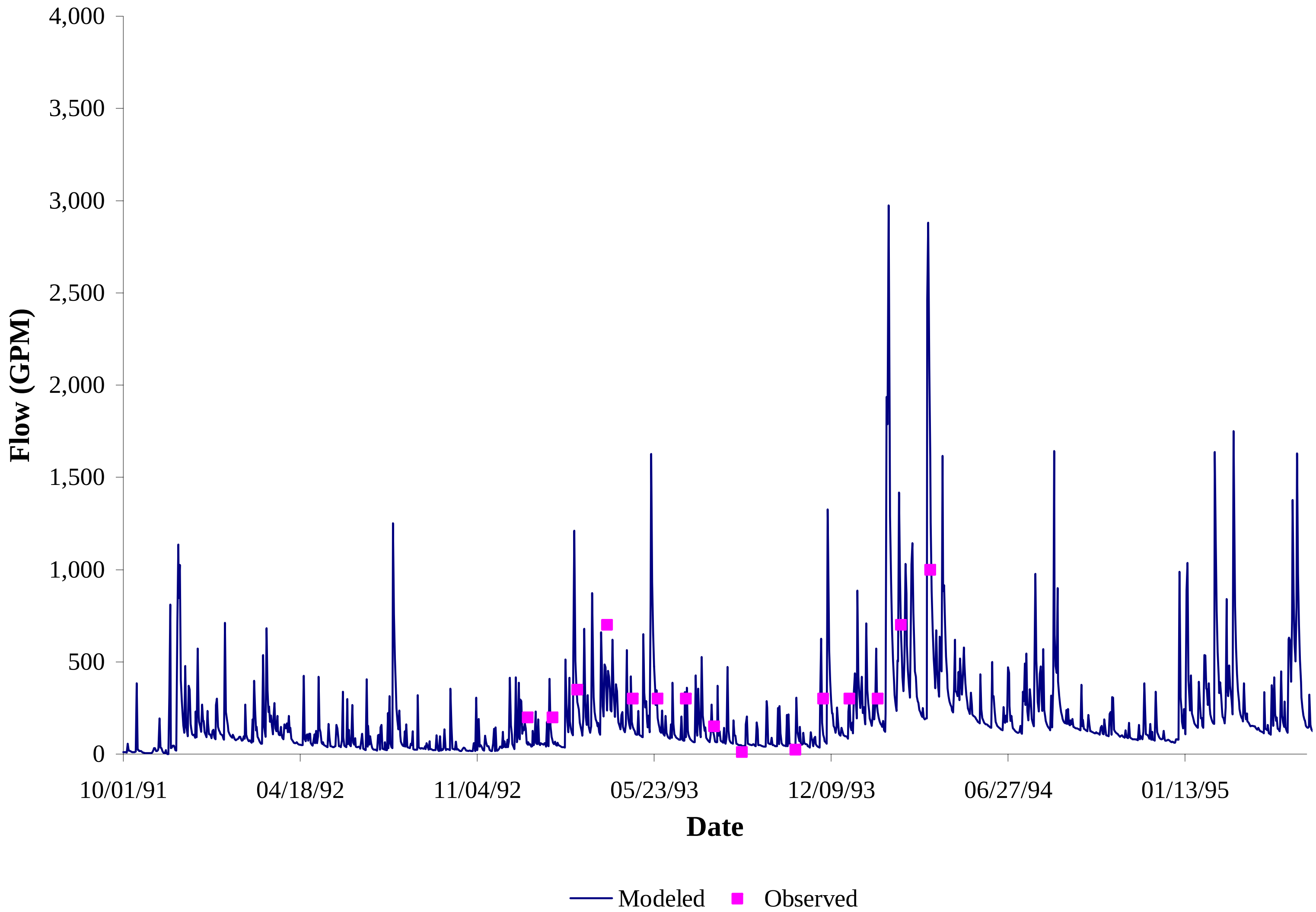


**Figure 4.9 Hydrologic Calibration results for period 10/1/91 through 6/30/95 at Reach 3.**

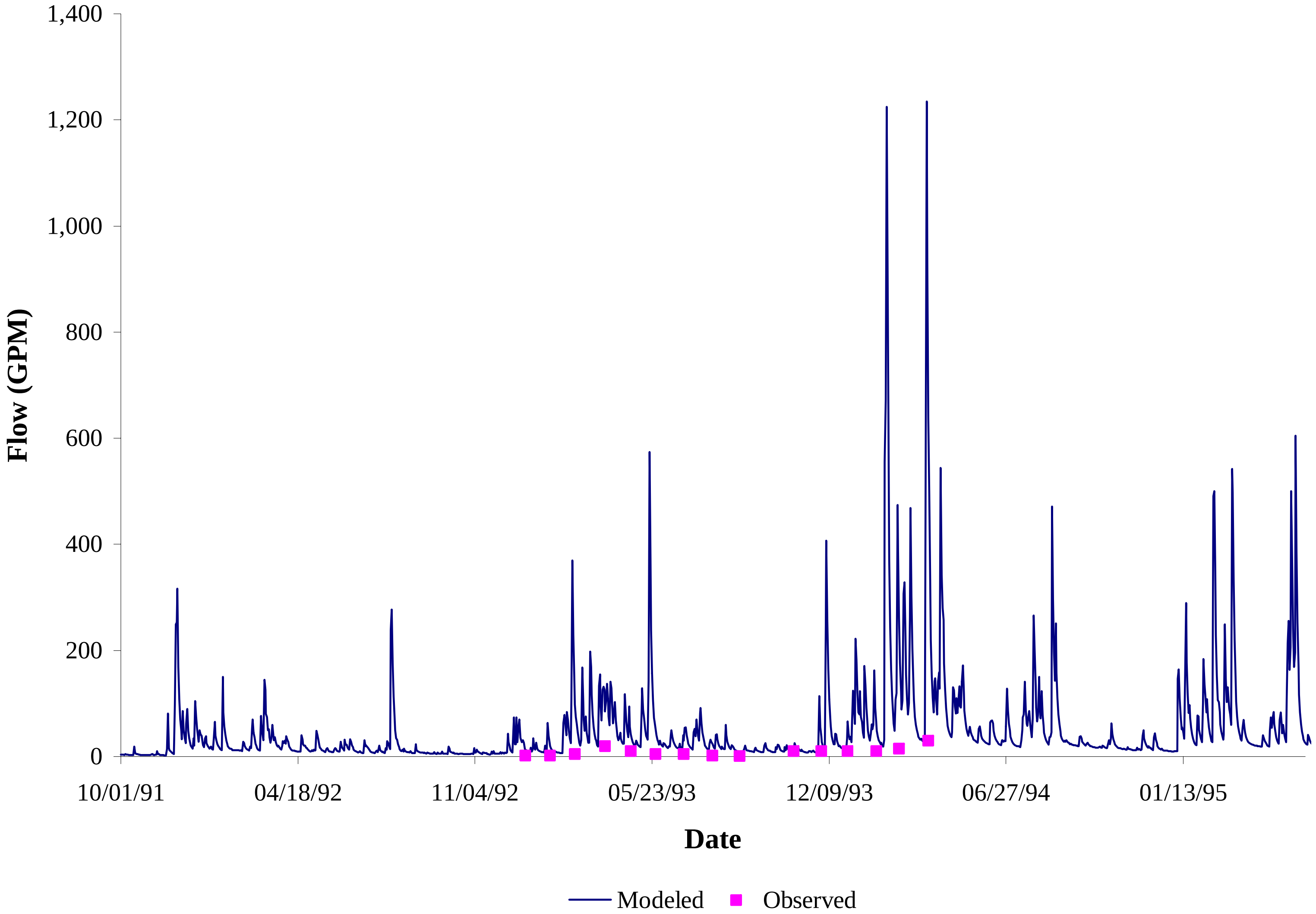


**Figure 4.10 Hydrologic Calibration results for period 10/1/91 through 6/30/95 at Reach 4.**

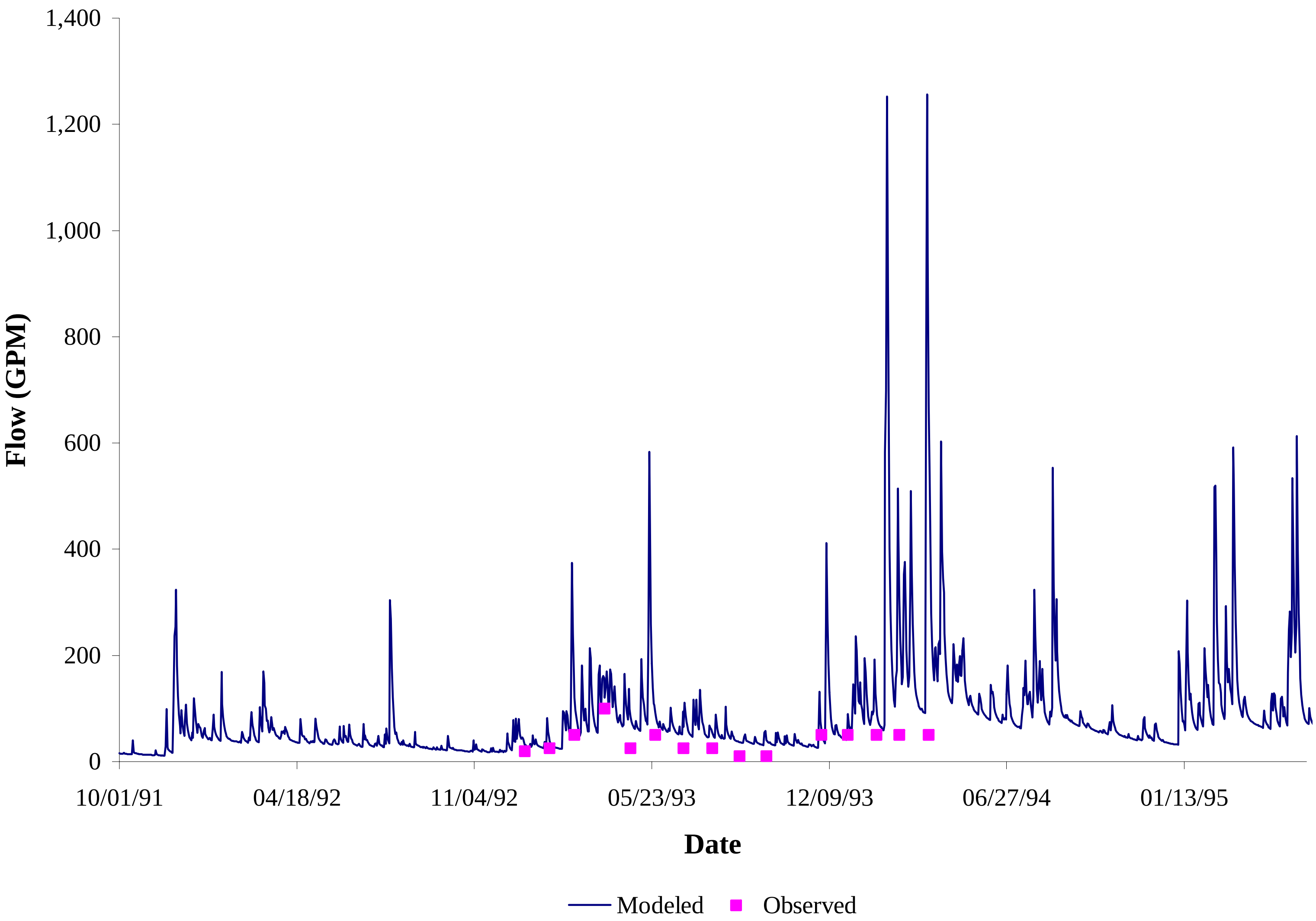


**Figure 4.11 Hydrologic Calibration results for period 10/1/91 through 6/30/95 at Reach 10.**

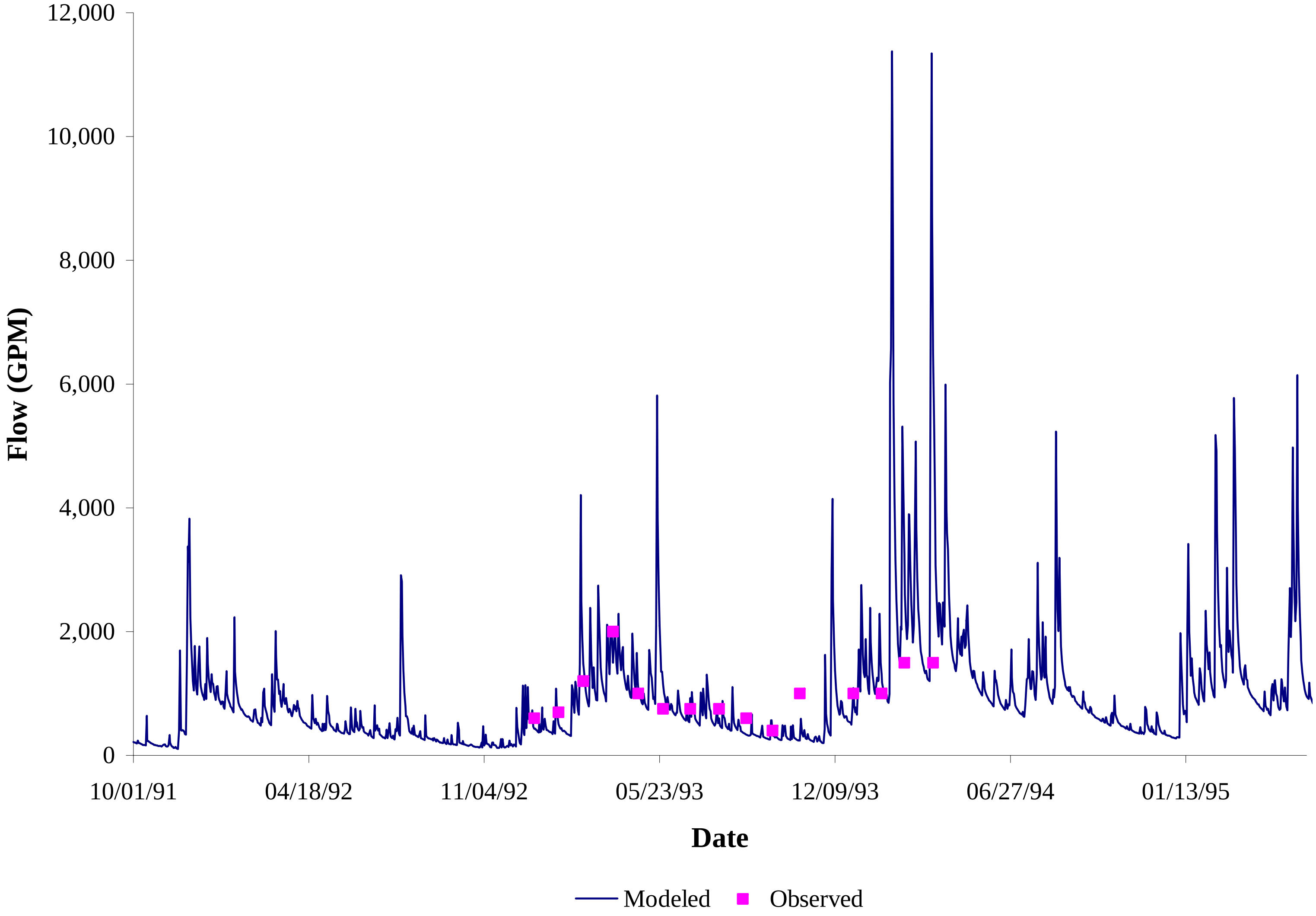


**Figure 4.12 Hydrologic Calibration results for period 10/1/91 through 6/30/95 at Reach 11.**

### 4.6.2 Water Quality Calibration

Water quality calibration is complicated by a number of factors, some of which are described here. First, water quality concentrations (e.g. dissolved Fe) are highly dependent on flow conditions. Any variability, associated with the modeling of stream flow, compounds variability in modeling water quality parameters. Second, the concentration of pollutants can be highly variable. Grab samples are collected at a specific point in time and space, while the model predicts concentrations averaged over the entire stream reach and the duration of the time-step.

With a successful hydrology calibration, the water quality model was then calibrated. The water quality calibration was conducted from 1/91 through 9/95. The process involves directly comparing modeled instream concentration to observed data and adjusting appropriate model parameters within reasonable ranges. Observed data was obtained from various sources as described in previous sections. As it was with the hydrologic calibration, the objective of the water quality calibration was to minimize the difference between observed and modeled concentrations. Results of the calibration are presented in Figures 4.13-4.44. All in-stream monitored acidity levels monitored during the calibration period were below the minimum detection level (MDL) of 1 mg $CaCO_3$/L. Modeled acidity was calibrated to levels below the MDL.

Careful visual inspection of graphical comparisons between continuous simulation results and limited observed points was the primary tool used to guide the calibration process. To provide a quantitative measure of the agreement between modeled and measured data while taking the inherent variability of pollutant concentrations into account, each observed value was compared with modeled concentrations in a 2-day window surrounding the observed data point. Standard error in each observation window was calculated as follows:

$$Standard\ Error = \frac{\sqrt{\dfrac{\sum_{i=1}^{n}\left(observed - modeled_i\right)^2}{(n-1)}}}{\sqrt{n}}$$

where

$$observed = \text{an observed value of fecal coliform}$$
$$modeled_i = \text{a modeled value in the 2-day window surrounding the observation}$$
$$n = \text{the number of modeled observations in the 2-day window}$$

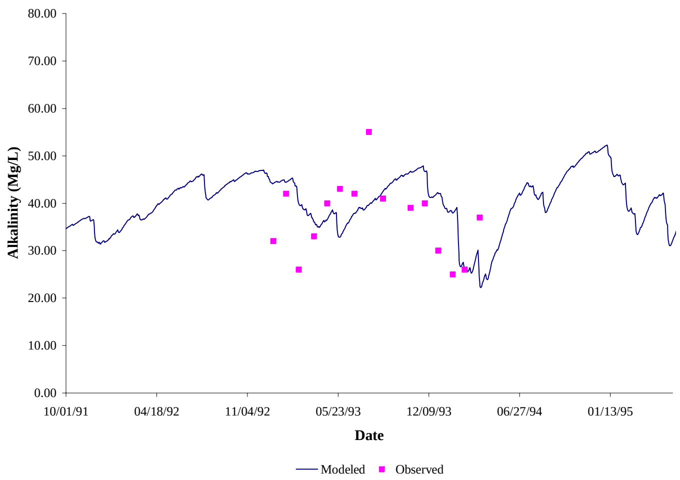


**Figure 4.13 Modeled and Observed Alkalinity Levels at Reach 3.**

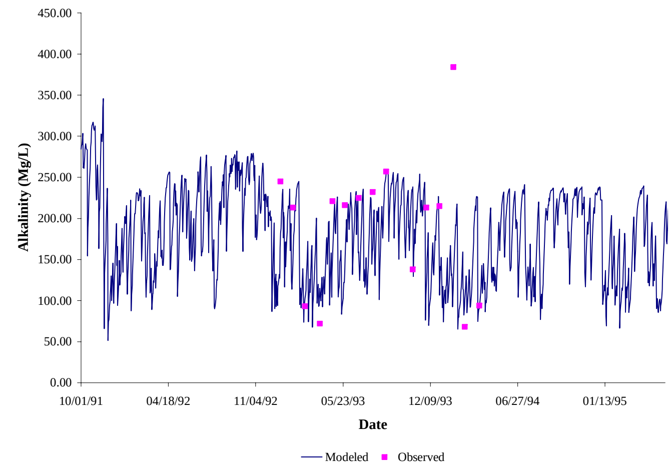


**Figure 4.15 Modeled and Observed Alkalinity Levels at Reach 4.**

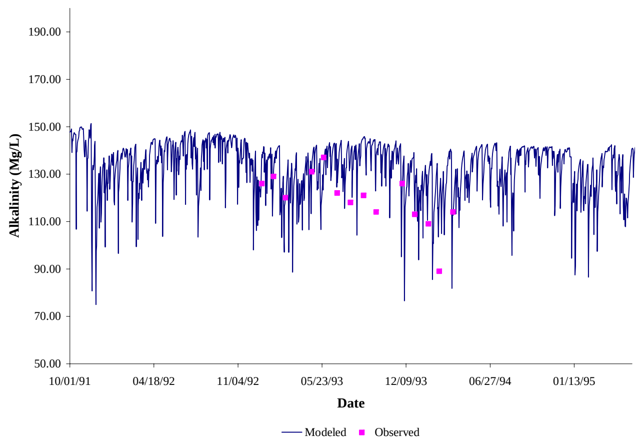


**Figure 4.14 Modeled and Observed Alkalinity Levels at Reach 10.**

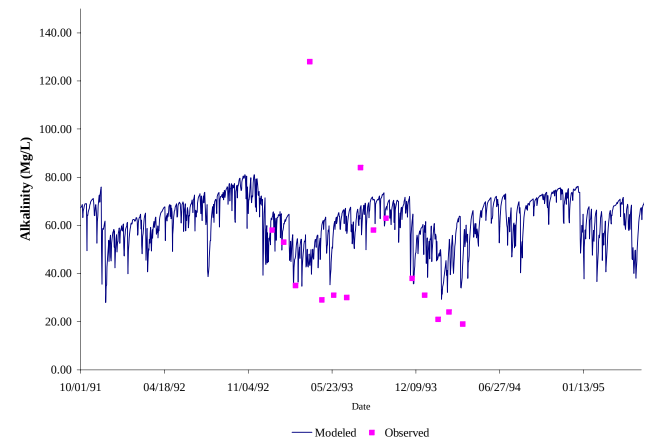


**Figure 4.16 Modeled and Observed Alkalinity Levels at Reach 11.**

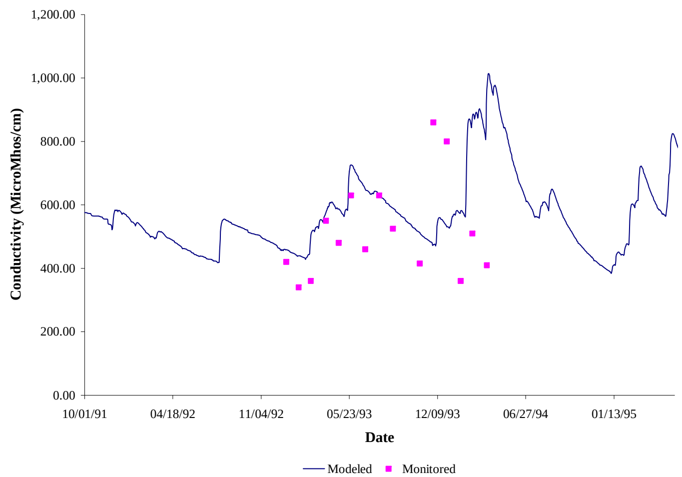


**Figure 4.17 Modeled and Observed Conductivity Levels at Reach 3.**

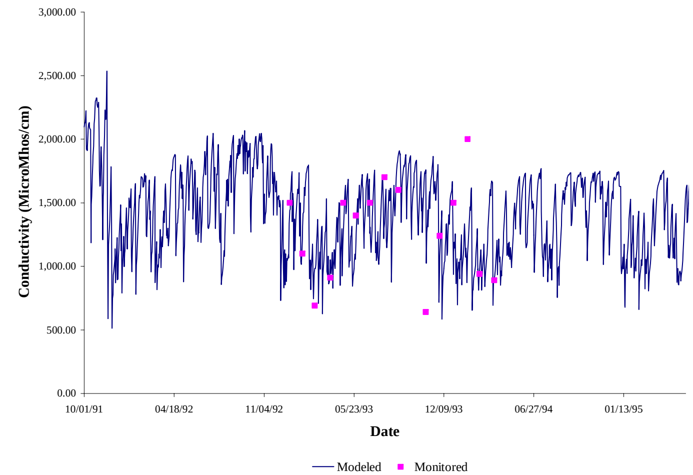


**Figure 4.19 Modeled and Observed Conductivity Levels at Reach 4.**

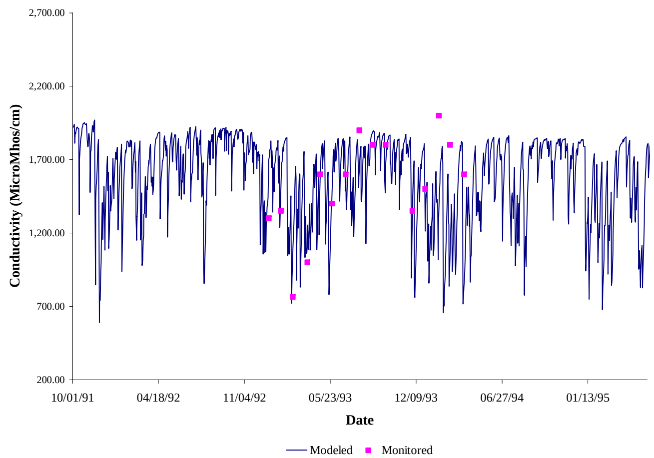


**Figure 4.18 Modeled and Observed Conductivity Levels at Reach 10.**

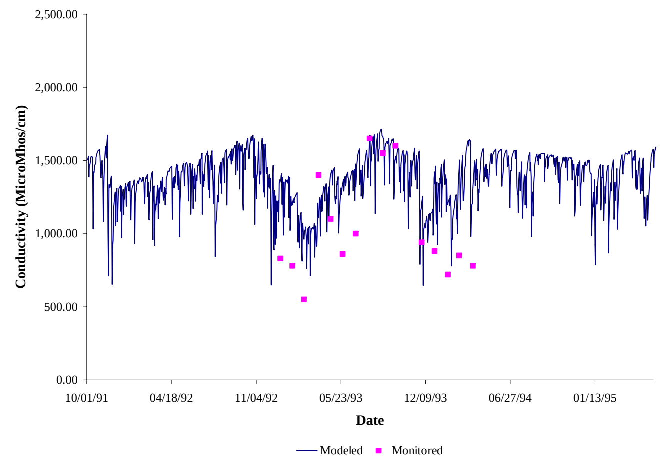


**Figure 4.20 Modeled and Observed Conductivity Levels at Reach 11.**

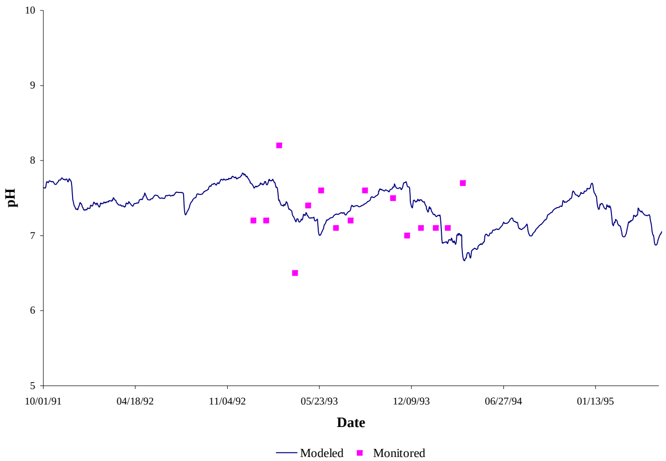


**Figure 4.21 Modeled and Observed pH Levels at Reach 3.**

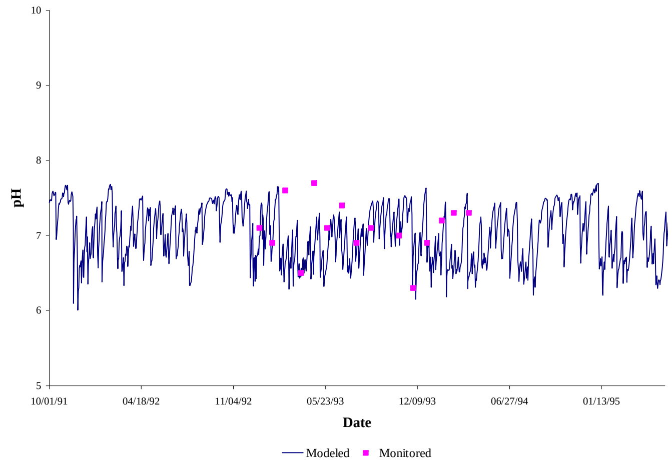


**Figure 4.23 Modeled and Observed pH Levels at Reach 4.**

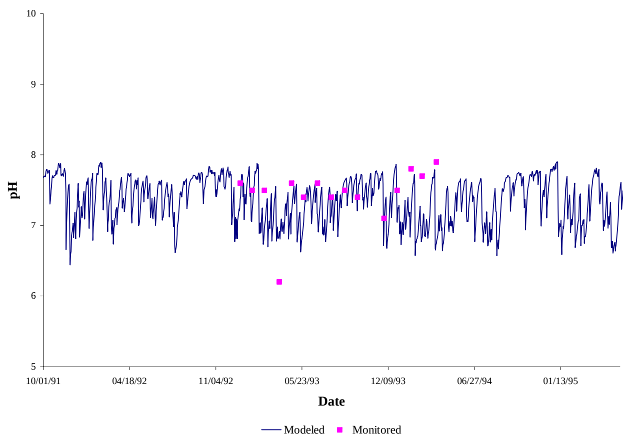


**Figure 4.22 Modeled and Observed pH Levels at Reach 10.**

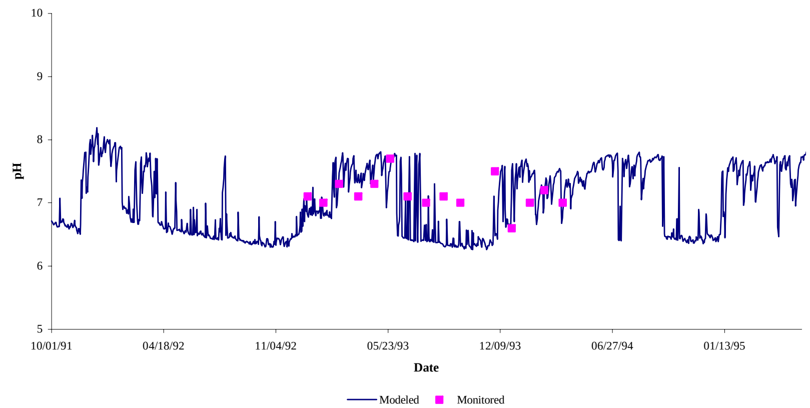


**Figure 4.24 Modeled and Observed pH Levels at Reach 11.**

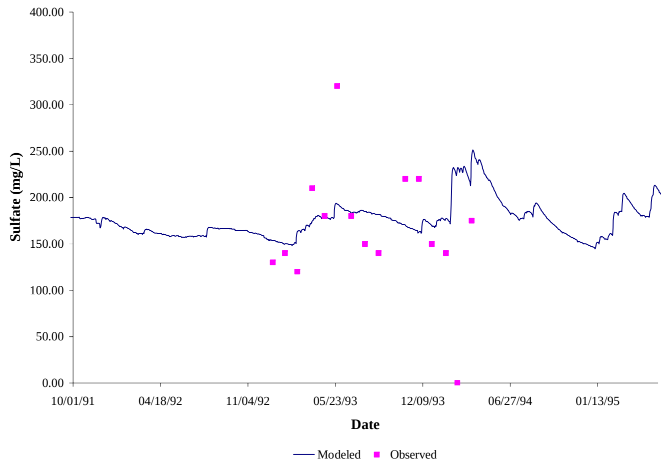


**Figure 4.25 Modeled and Observed Sulfate Levels at Reach 3.**

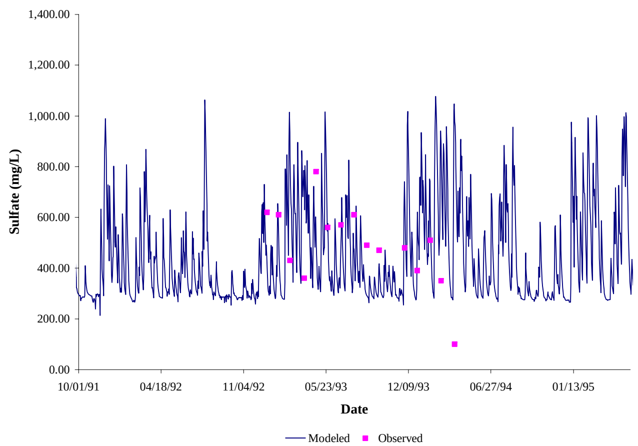


**Figure 4.26 Modeled and Observed Sulfate Levels at Reach 10.**

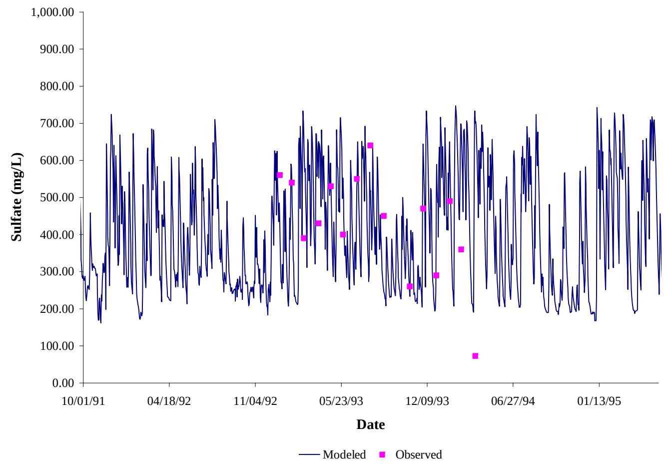


**Figure 4.27 Modeled and Observed Sulfate Levels at Reach 4.**

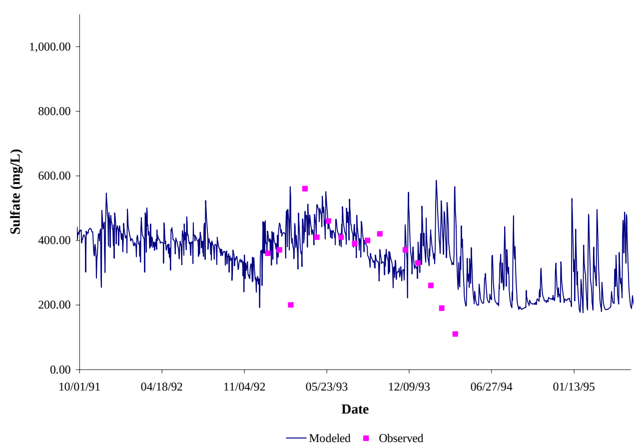


**Figure 4.28 Modeled and Observed Sulfate Levels at Reach 11.**

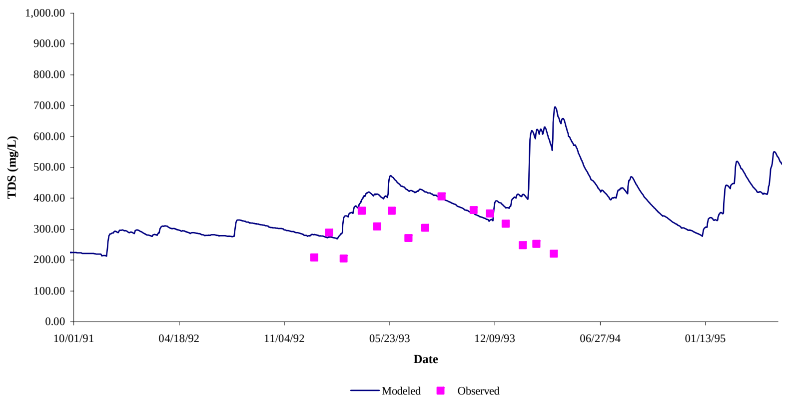


**Figure 4.29 Modeled and Observed Total Dissolved Solids Levels at Reach 3.**

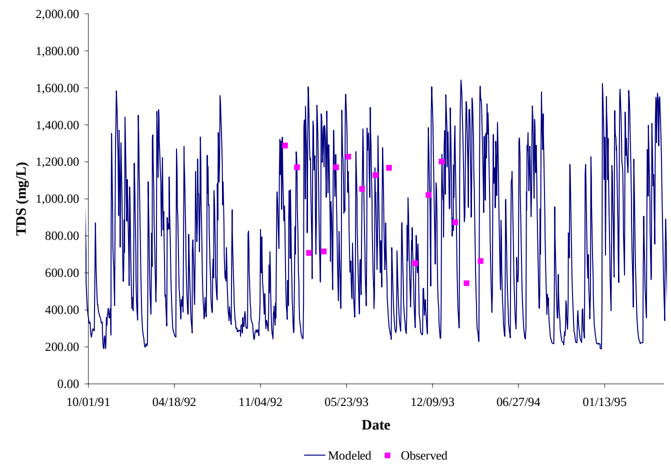


**Figure 4.31 Modeled and Observed Total Dissolved Solids Levels at Reach 4.**

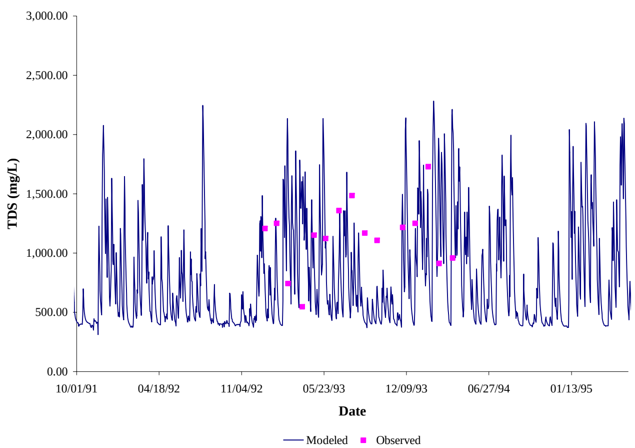


**Figure 4.30 Modeled and Observed Total Dissolved Solids Levels at Reach 10.**

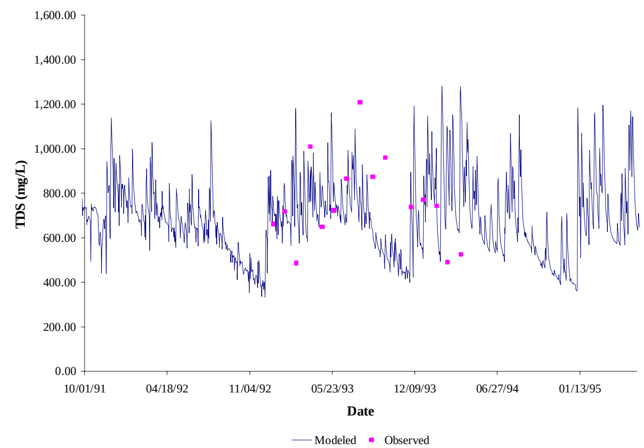


**Figure 4.32 Modeled and Observed Total Dissolved Solids Levels at Reach 11.**

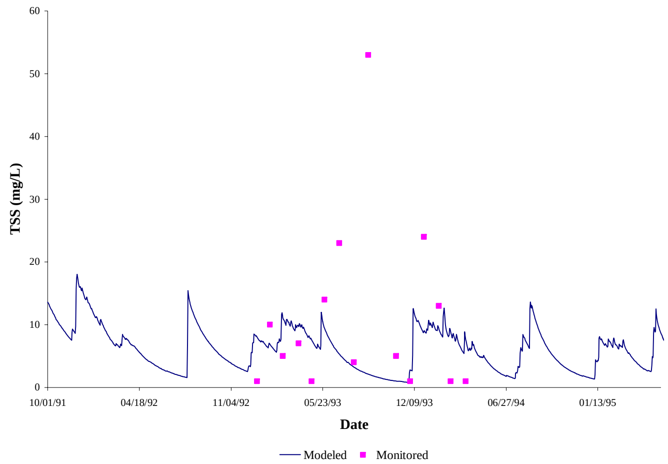


**Figure 4.33 Modeled and Observed Total Suspended Solids Levels at Reach 3.**

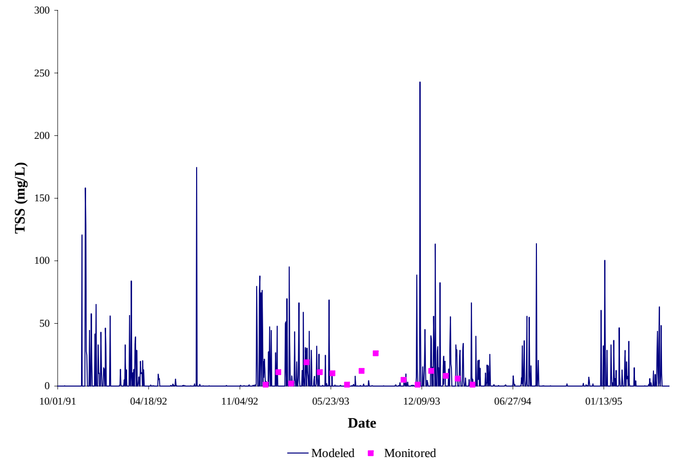


**Figure 4.35 Modeled and Observed Total Suspended Solids Levels at Reach 4.**

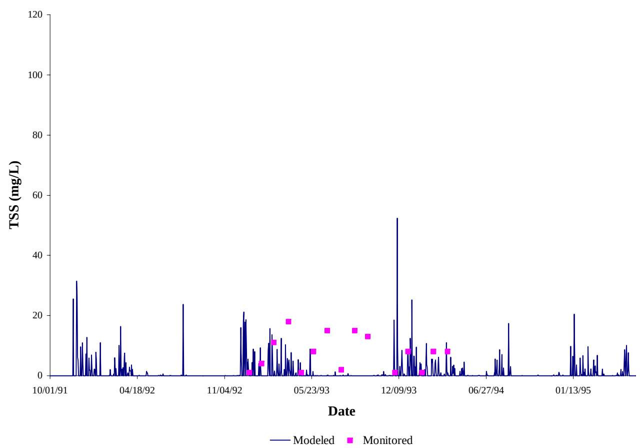


**Figure 4.34 Modeled and Observed Total Suspended Solids Levels at Reach 10.**

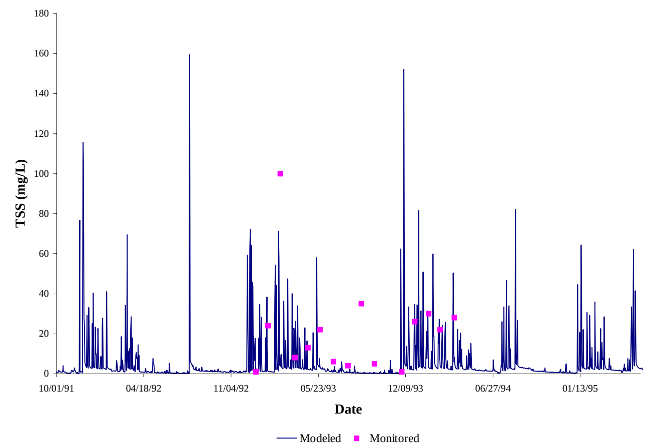


**Figure 4.36 Modeled and Observed Total Suspended Solids Levels at Reach 11**

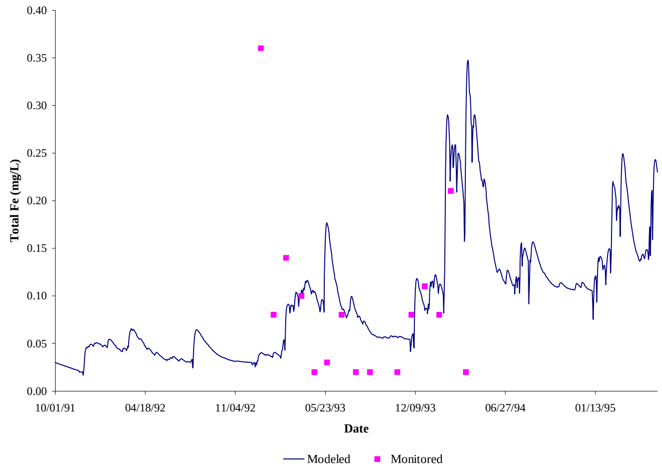


**Figure 4.37 Modeled and Observed Iron Levels at Reach 3.**

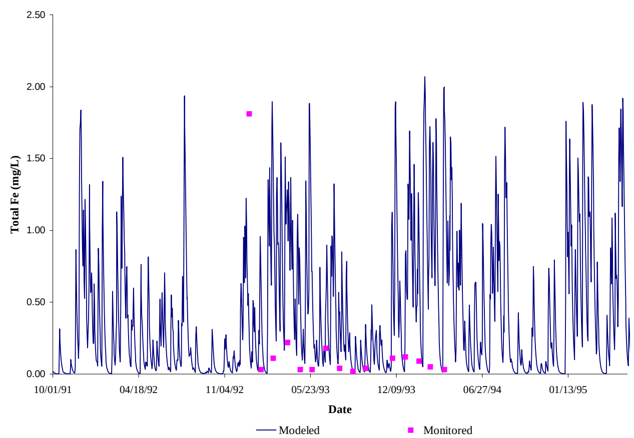


**Figure 4.38 Modeled and Observed Iron Levels at Reach 10.**

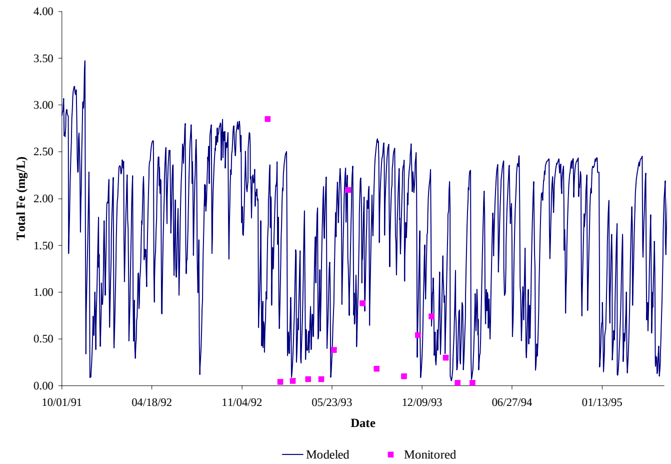


**Figure 4.39 Modeled and Observed Iron Levels at Reach 4.**

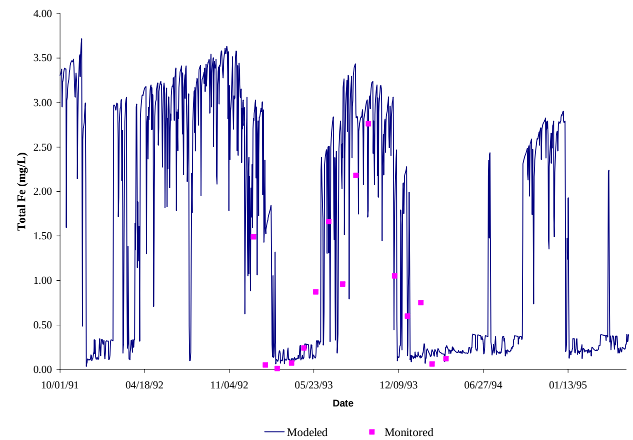


**Figure 4.40 Modeled and Observed Iron Levels at Reach 11.**

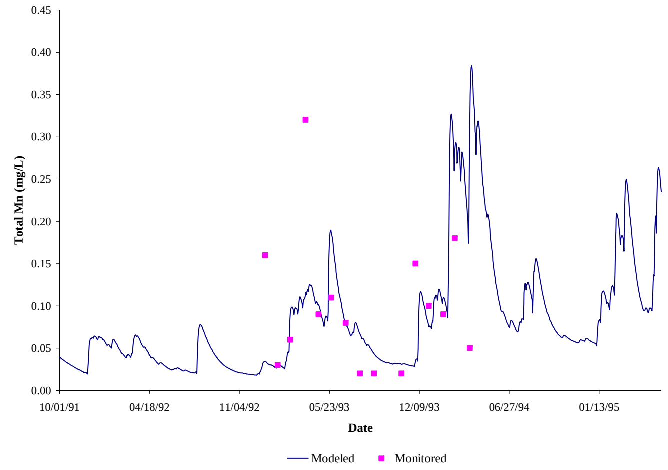


**Figure 4.41 Modeled and Observed Manganese Levels at Reach 3.**

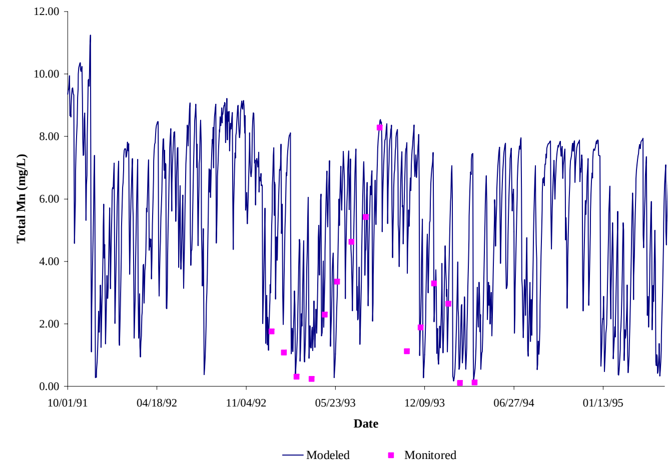


**Figure 4.43 Modeled and Observed Manganese Levels at Reach 4.**

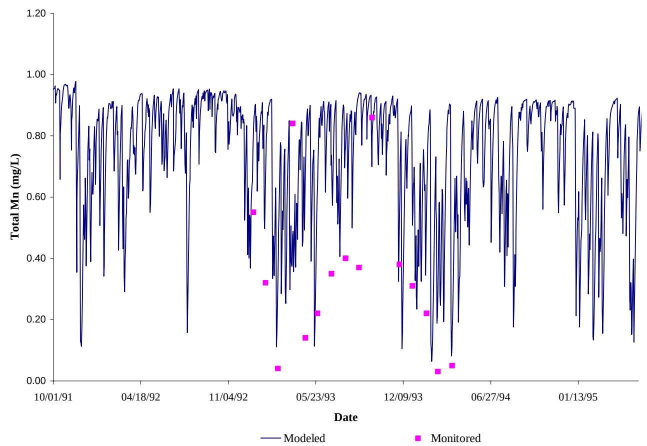


**Figure 4.42 Modeled and Observed Manganese Levels at Reach 10.**

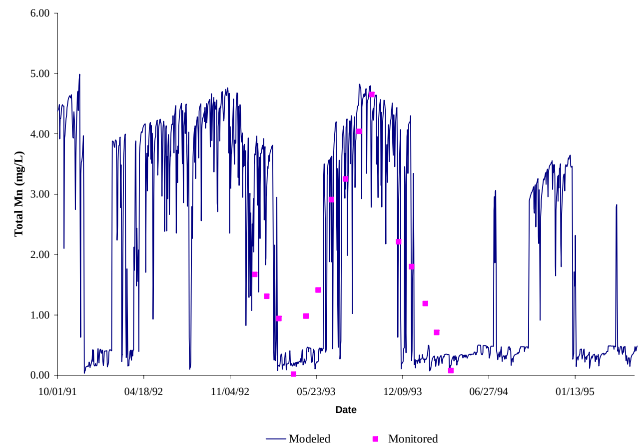


**Figure 4.44 Modeled and Observed Manganese Levels at Reach 11.**

This is a non-traditional use of standard error, applied here to offer a quantitative measure of model accuracy. In this context, standard error measures the variability of the sample mean of the modeled values about an instantaneous observed value. The use of limited instantaneous observed values to evaluate continuous data introduces error and therefore increases standard error. The mean of all standard errors for each station analyzed was calculated. (Table 4.5).

**Table 4.5 Results of standard error analyses on calibration runs.**

| | ***Subwatershed*** | **3** | **4** | **10** | **11** |
|---|---|---|---|---|---|
| | ***Milepoint*** | **3.32** | **3.20+0.05** | **2.10+0.04** | **1.34** |
| *Constituent* | *Units* | | | | |
| Alkalinity | mg-$CaCO_3$/L | 0.283 | 1.481 | 0.539 | 0.489 |
| Conductivity | μmhos/cm | 3.647 | 7.168 | 7.352 | 7.205 |
| pH | SU | 0.009 | 0.009 | 0.008 | 0.009 |
| Sulfate | mg/L | 1.286 | 4.289 | 5.542 | 2.944 |
| TDS | mg/L | 2.795 | 9.691 | 11.485 | 4.607 |
| TSS | mg/L | 0.279 | 0.238 | 0.544 | 0.416 |
| Total Fe | mg/L | 0.003 | 0.069 | 0.012 | 0.044 |
| Total Mn | mg/L | 0.002 | 0.039 | 0.012 | 0.015 |

## 4.7 Existing Conditions

For the development of the TMDL, existing conditions were set to conditions observed during the assessment period (i.e. 10/91-9/95). All remaining model runs were conducted using precipitation data for the time period 10/91 through 9/95. Figures 4.45-4.55 show the existing conditions for the various stressors. Modeled concentrations for existing conditions were linked to the biometrics resulting in a time-series of existing bioassessment conditions. Figure 4.56 shows an example of an output time-series for Reach 5. A box and whisker plot showing modeled bioassessments for three locations on Black Creek is shown in Figure 4.57. The resulting modeled bioassessments for Black Creek agree with monitored bioassessments conducted in the watershed (i.e. moderately impaired).

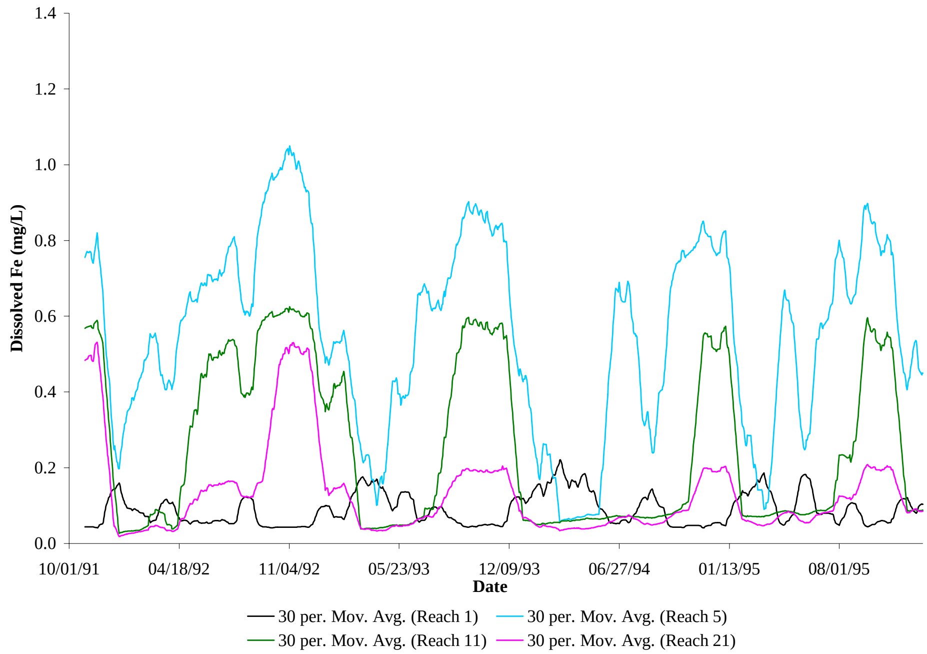


**Figure 4.45 Thirty-day average existing dissolved iron levels modeled at four sites in Black Creek using precipitation inputs for October 1991 through June 1995.**

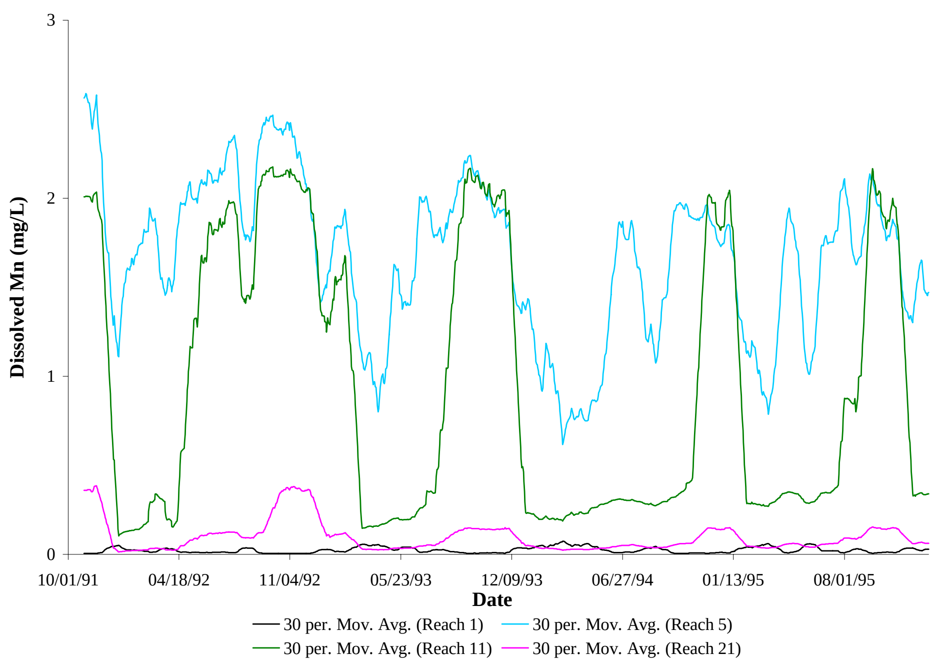


**Figure 4.46 Thirty-day average existing dissolved manganese levels modeled at four sites in Black Creek using precipitation inputs for October 1991 through June 1995.**

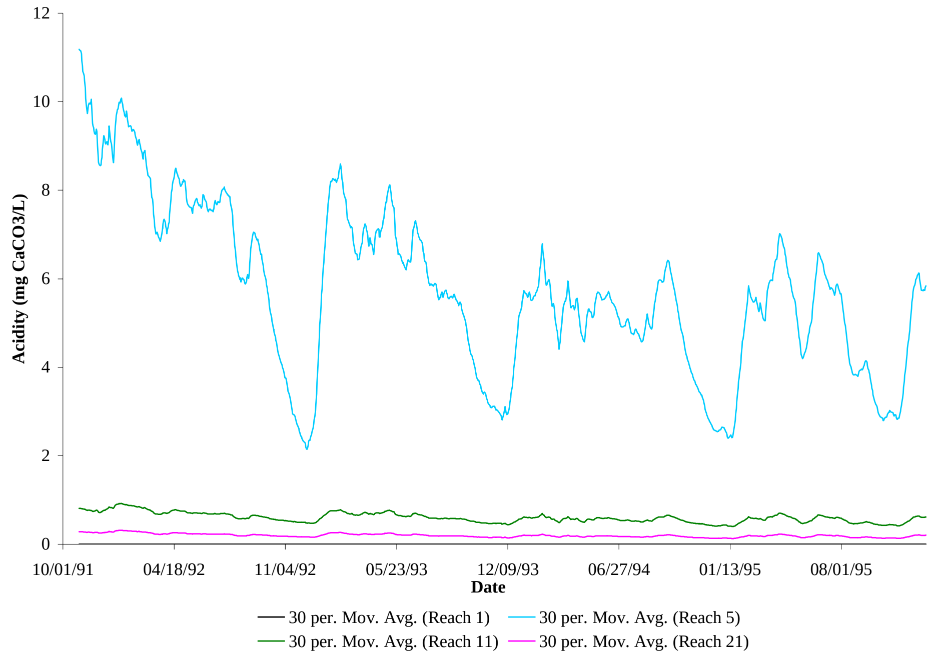


**Figure 4.47 Thirty-day average existing acidity levels modeled at four sites in Black Creek using precipitation inputs for October 1991 through June 1995.**

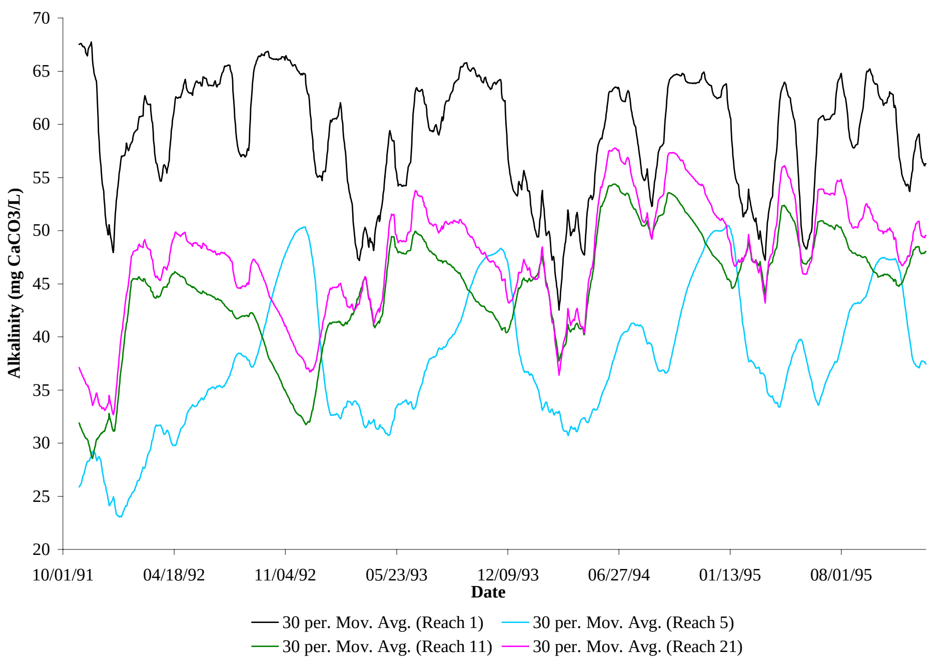


**Figure 4.48 Thirty-day average existing alkalinity levels modeled at four sites in Black Creek using precipitation inputs for October 1991 through June 1995.**

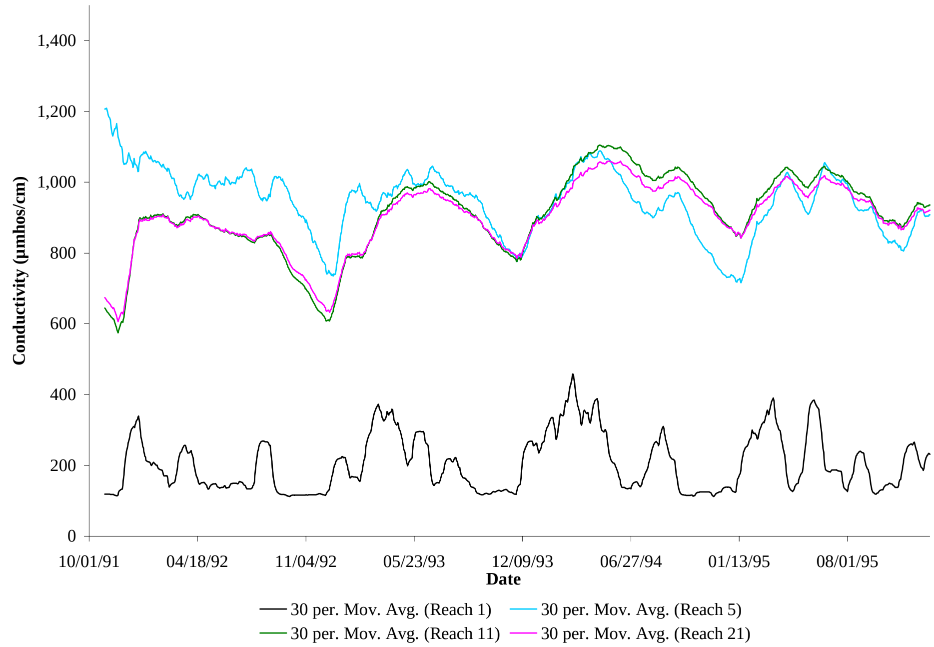


**Figure 4.49 Thirty-day average existing conductivity levels modeled at four sites in Black Creek using precipitation inputs for October 1991 through June 1995.**

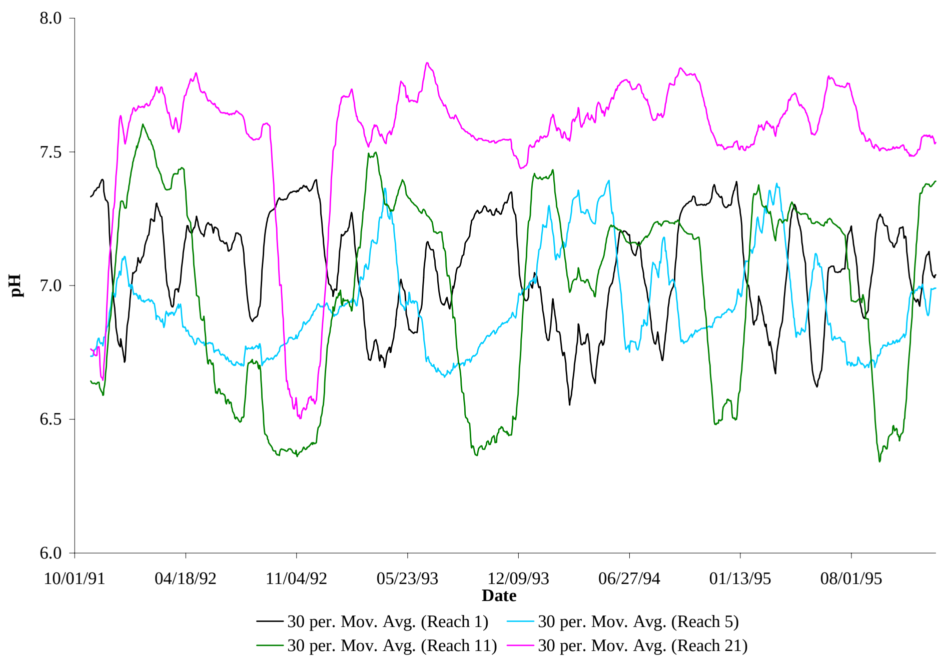


**Figure 4.50 Thirty-day average existing pH levels modeled at four sites in Black Creek using precipitation inputs for October 1991 through June 1995.**

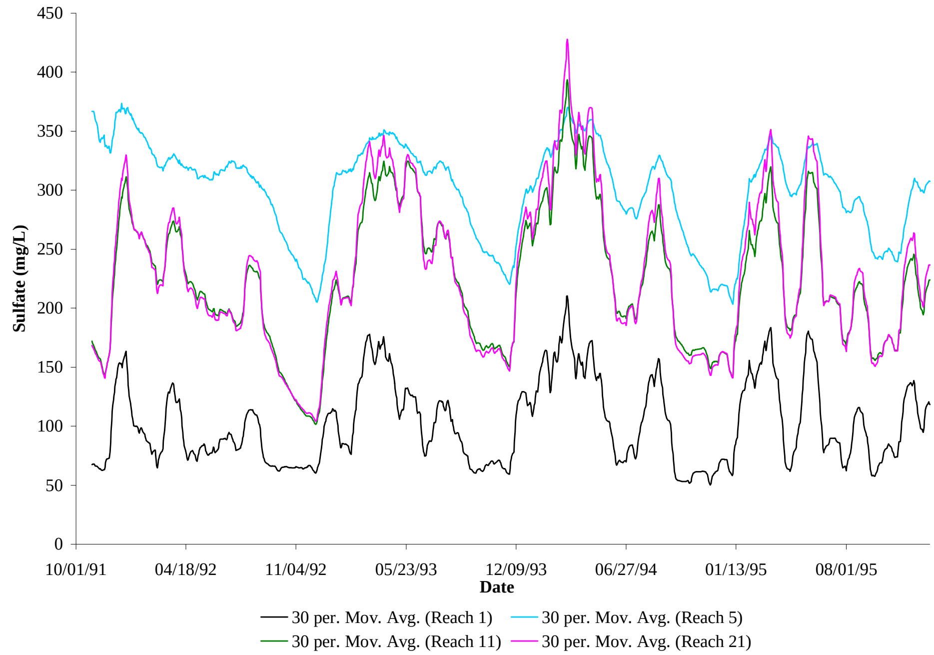


**Figure 4.51 Thirty-day average existing sulfate levels modeled at four sites in Black Creek using precipitation inputs for October 1991 through June 1995.**

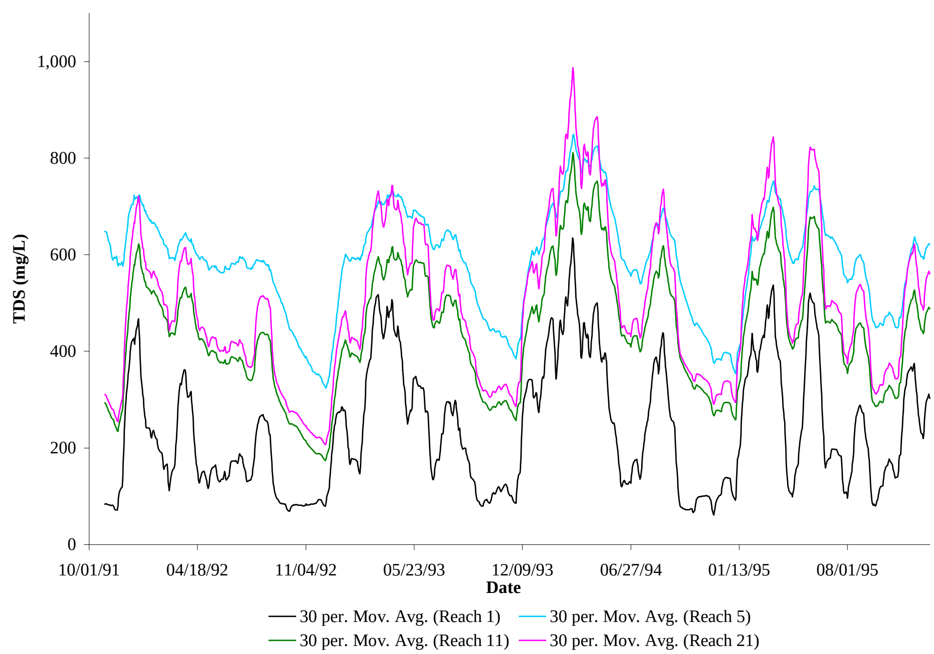


**Figure 4.52 Thirty-day average existing total dissolved solids levels modeled at four sites in Black Creek using precipitation inputs for October 1991 through June 1995.**

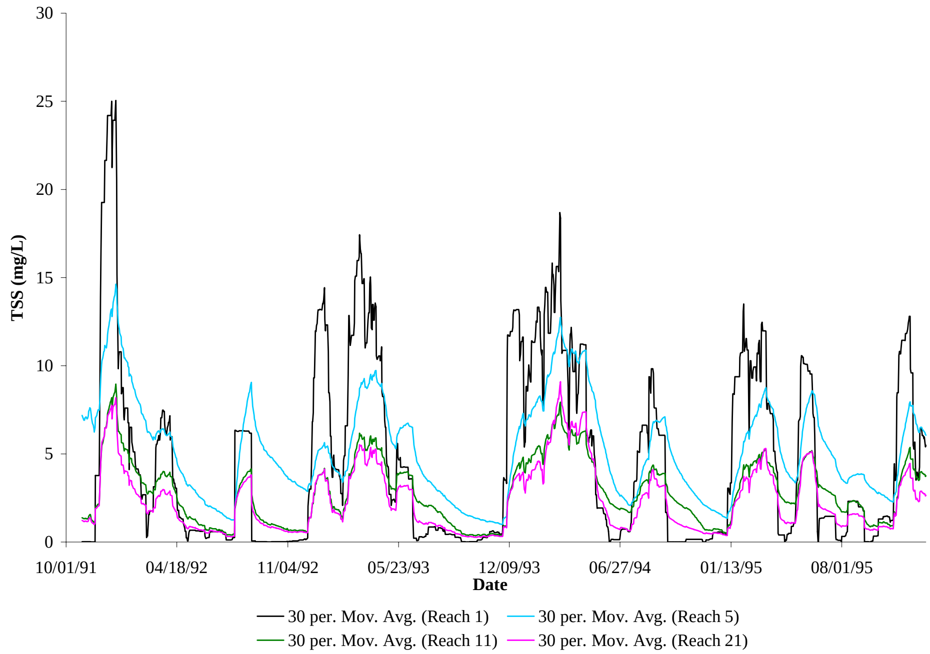


**Figure 4.53 Thirty-day average existing total suspended solids levels modeled at four sites in Black Creek using precipitation inputs for October 1991 through June 1995.**

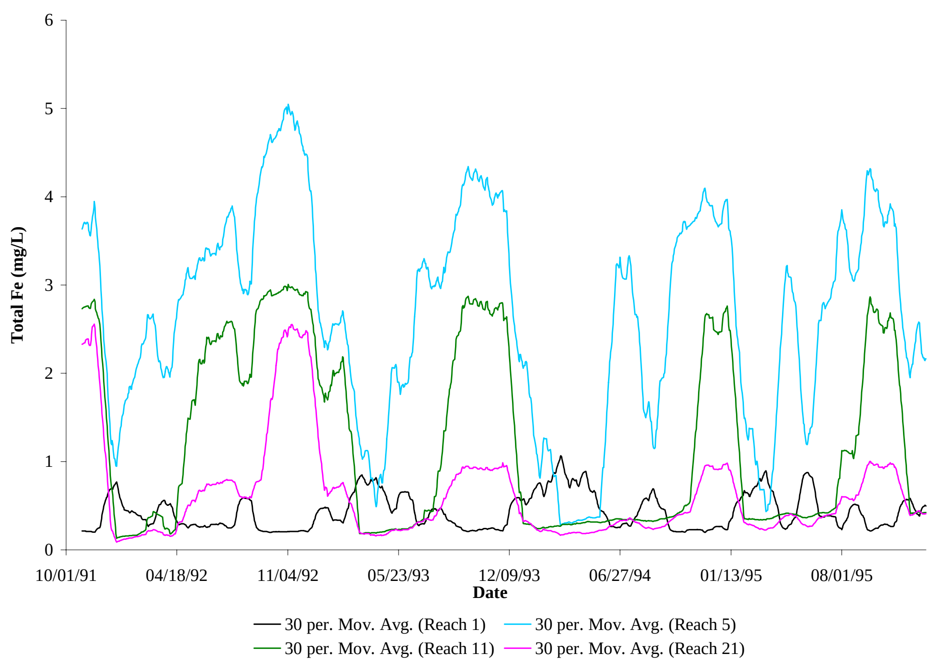


**Figure 4.54 Thirty-day average existing total iron levels modeled at four sites in Black Creek using precipitation inputs for October 1991 through June 1995.**

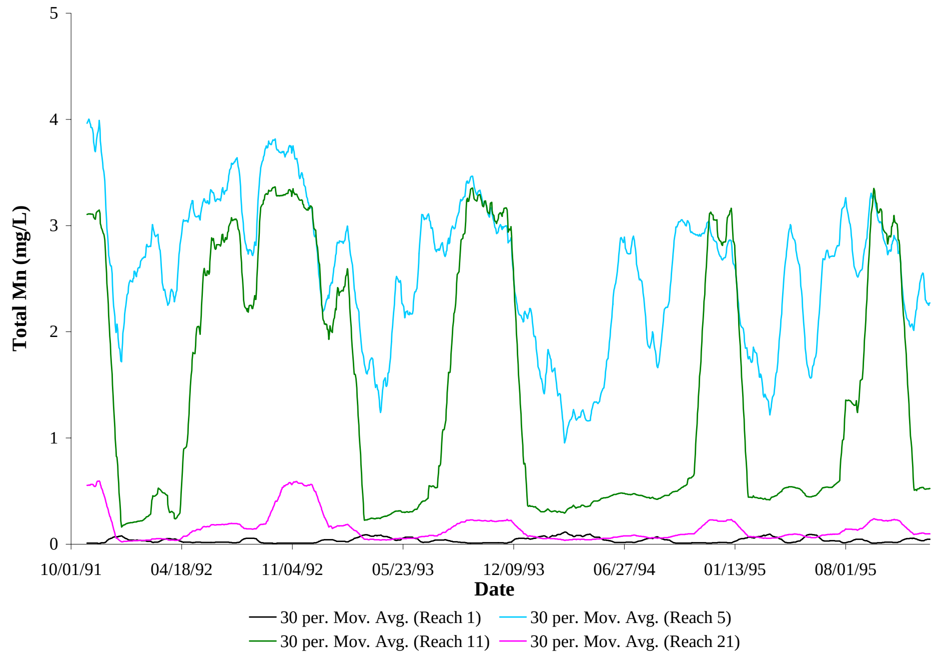


**Figure 4.55 Thirty-day average existing total manganese levels modeled at four sites in Black Creek using precipitation inputs for October 1991 through June 1995.**

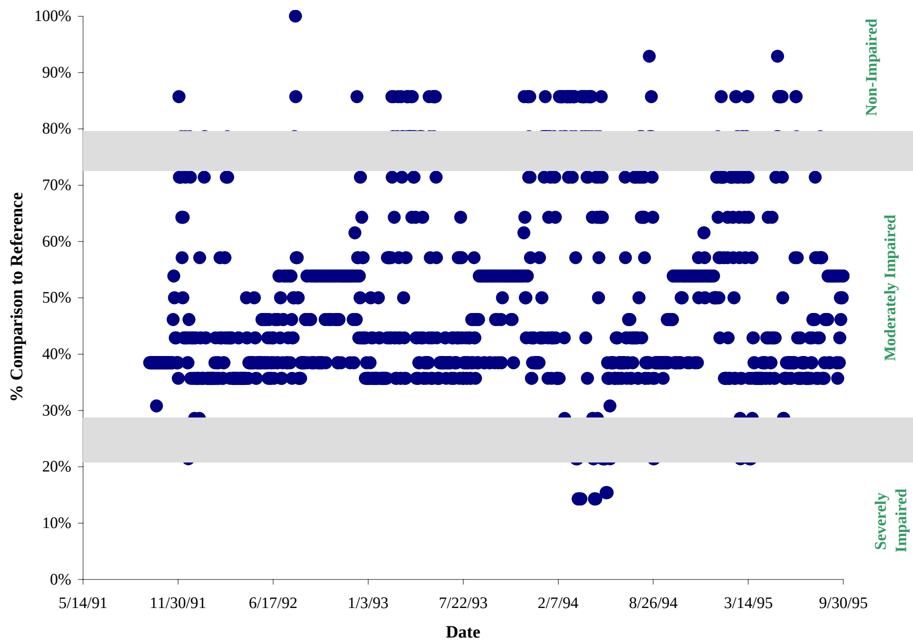


**Figure 4.56 Modeled bioassessment for reach 5 representing existing conditions.**

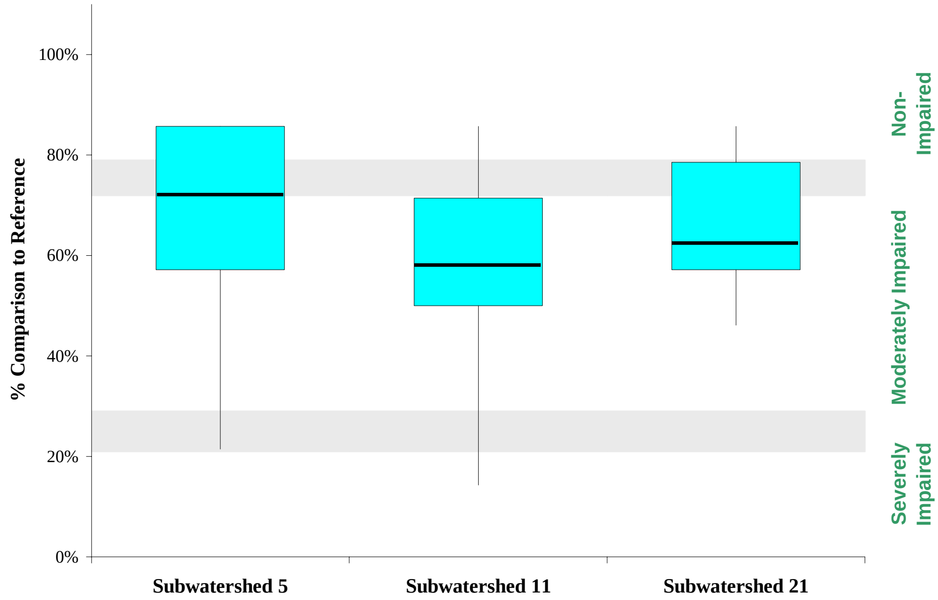


**Figure 4.57 Modeled bioassessments for three stations in Black Creek representing existing conditions.**

# 5. ALLOCATION

Total Maximum Daily Loads (TMDLs) consist of waste load allocations (WLAs, i.e. point sources) and load allocations (LAs, i.e. nonpoint sources) including natural background levels. Additionally, the TMDL must include a margin of safety (MOS) that either implicitly or explicitly accounts for the uncertainties in the process. The definition is typically denoted by the expression:

$$TMDL = WLAs + LAs + MOS$$

The TMDL becomes the amount of a pollutant that can be assimilated by the receiving waterbody and still achieve water quality standards. For general standard impairments, the TMDL is expressed in terms of loads (e.g. kg/day) or resulting concentration (e.g. mg/L). A sensitivity analysis was performed to determine the impact of uncertainties in input parameters.

## *5.1 Sensitivity Analysis*

Sensitivity analyses were conducted to assess the impact of unknown variability in source allocation (e.g., seasonal and spatial variability of background loads, and point source loads). Since the general standard is based on aquatic life rather than pollutant loadings, it was considered necessary to analyze the effect of source changes on the biological assessment (i.e. benthic macroinvertebrate community).

An initial base run was performed using observed chemical data from Black Creek's reference station (i.e. UBC-1) and a target station in the lower Black Creek (i.e. LBC-4). Perturbations to the base condition at the target station for each stressor were made and entered in the biometrics models, producing a bioassessment score relative to the reference station. Deviations from the base run are plotted in Figures 5.1 through 5.11.

These analyses focused on one stressor at a time, and thereby do not explore the cumulative impact of multiple stressor variations. However, these plots do lend insight into the expected variability of the bioassessment model.

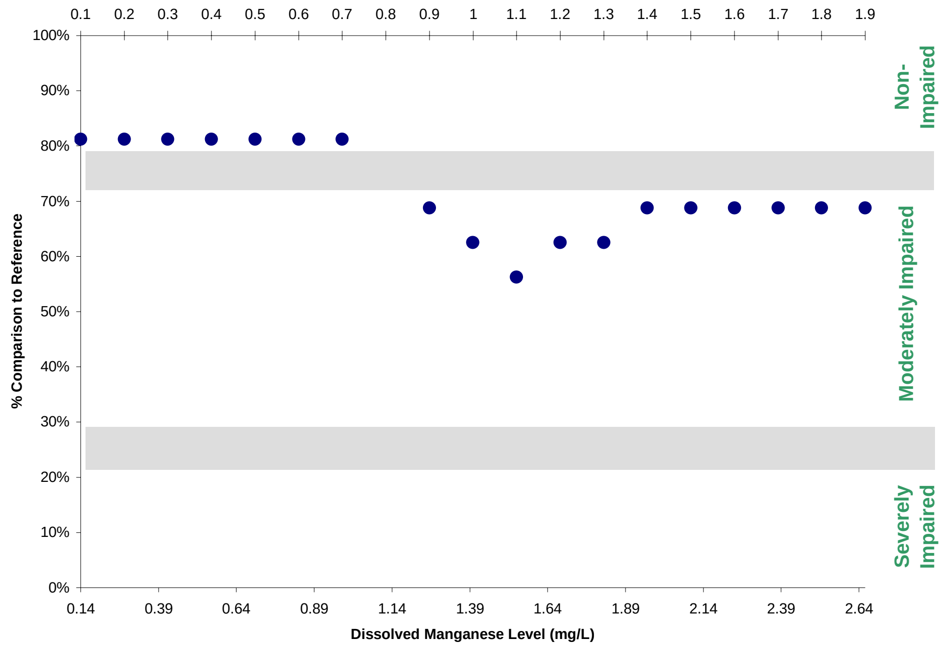


**Figure 5.1 Bioassessment response to changes in Dissolved Manganese level**

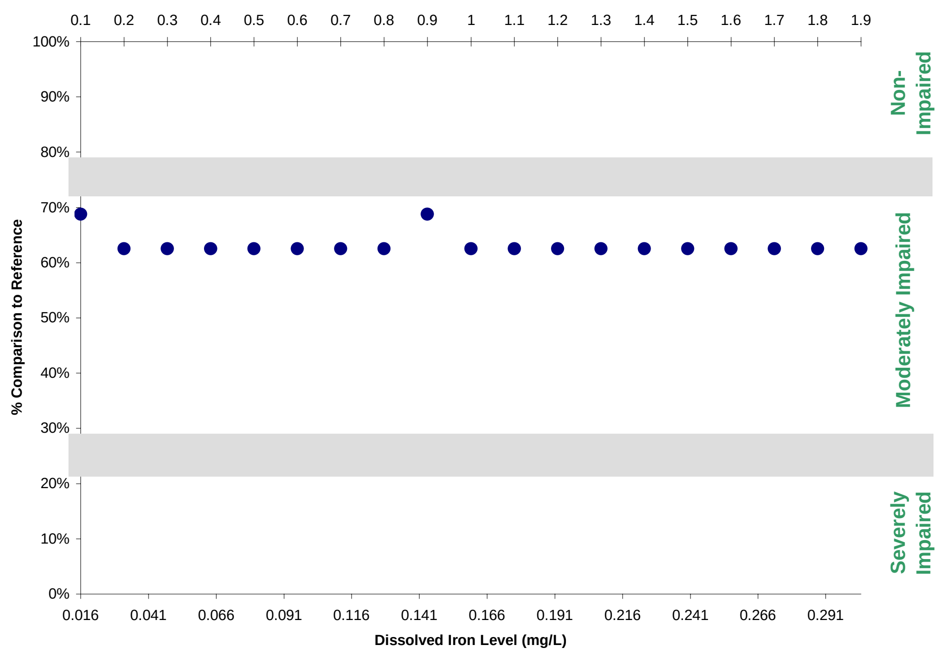


**Figure 5.2 Bioassessment response to changes in Dissolved Iron level.**

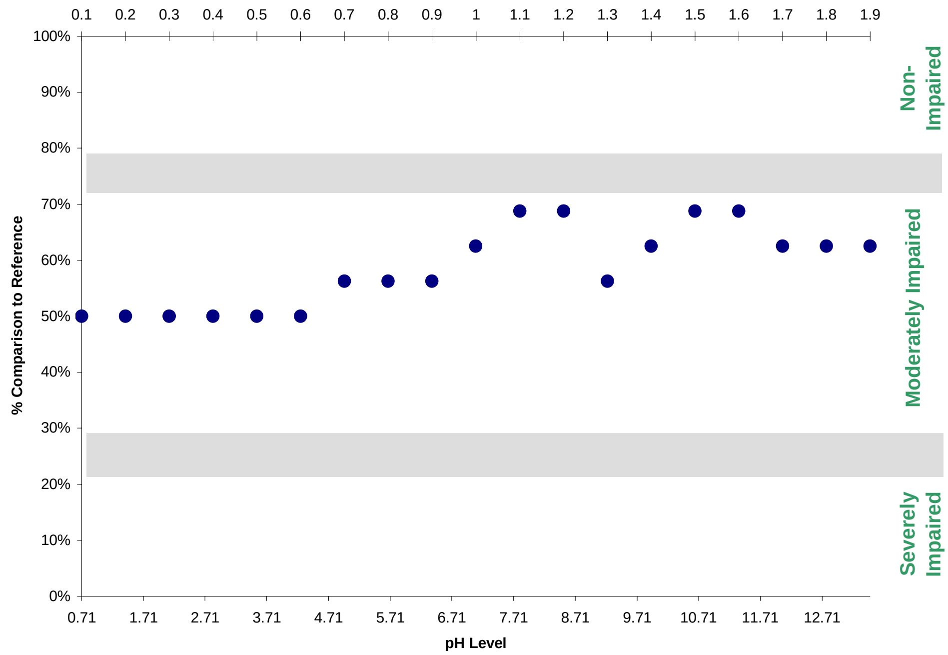


**Figure 5.3 Bioassessment response to changes in pH level**

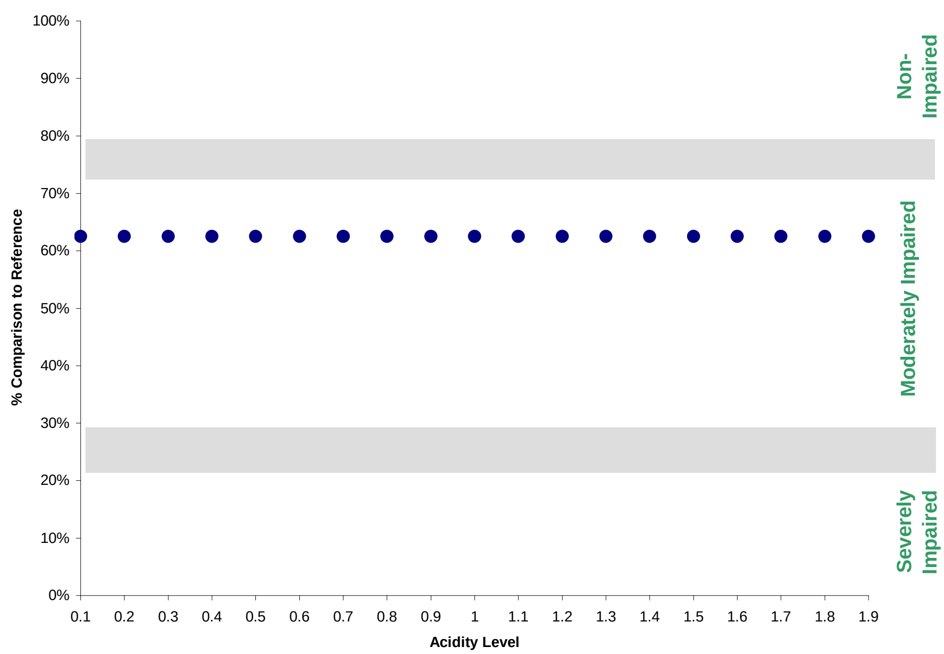


**Figure 5.4 Bioassessment response to changes in Acidity level**

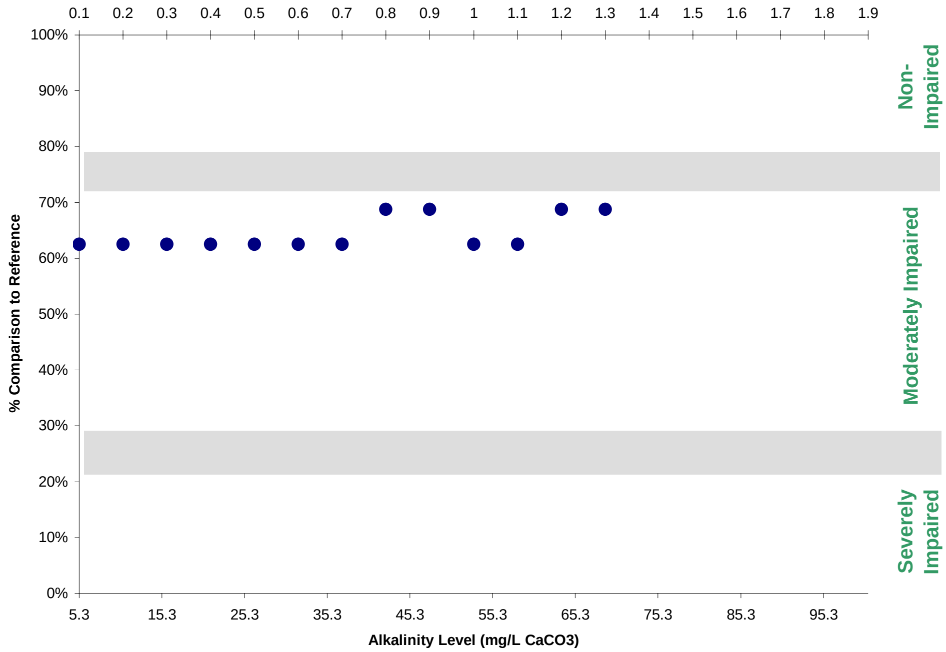


**Figure 5.5 Bioassessment response to changes in Alkalinity level (mg/L CaCO3)**

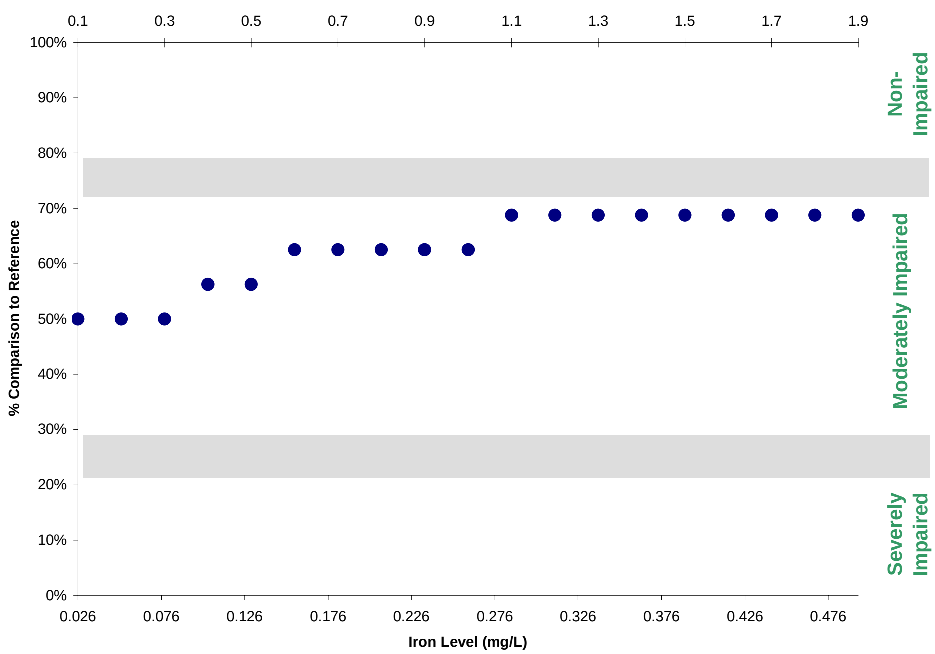


**Figure 5.6 Bioassessment response to changes in Iron level**

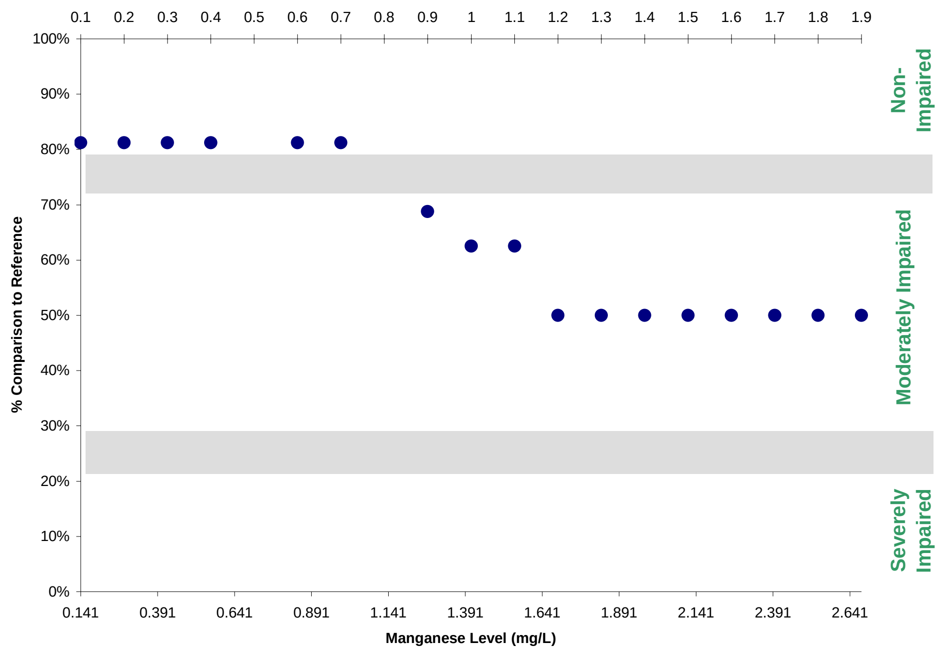


**Figure 5.7 Bioassessment response to changes in Manganese level (mg/L)**

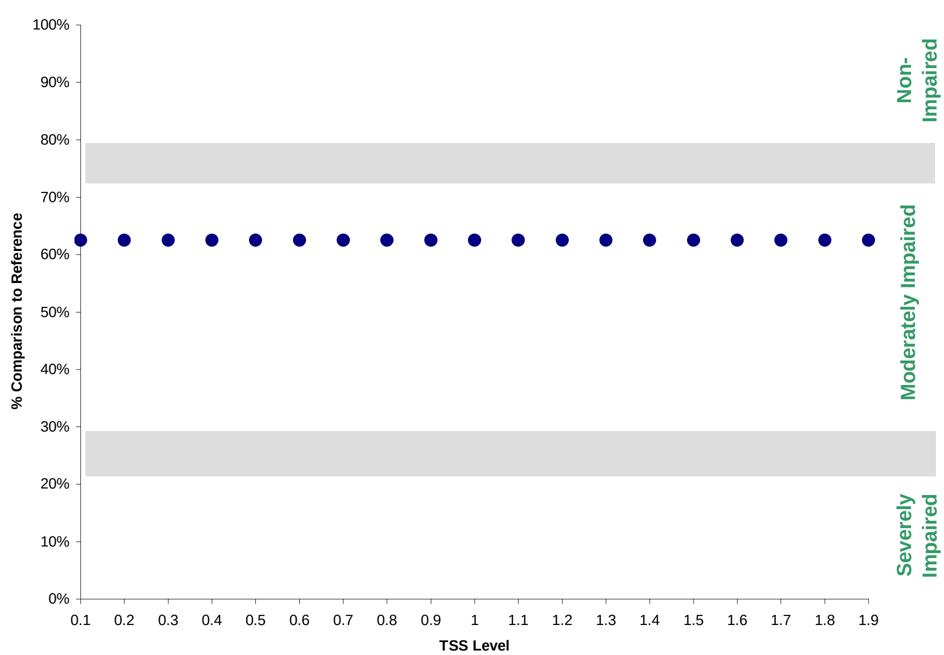


**Figure 5.8 Bioassessment response to changes in TSS level (mg/L)**

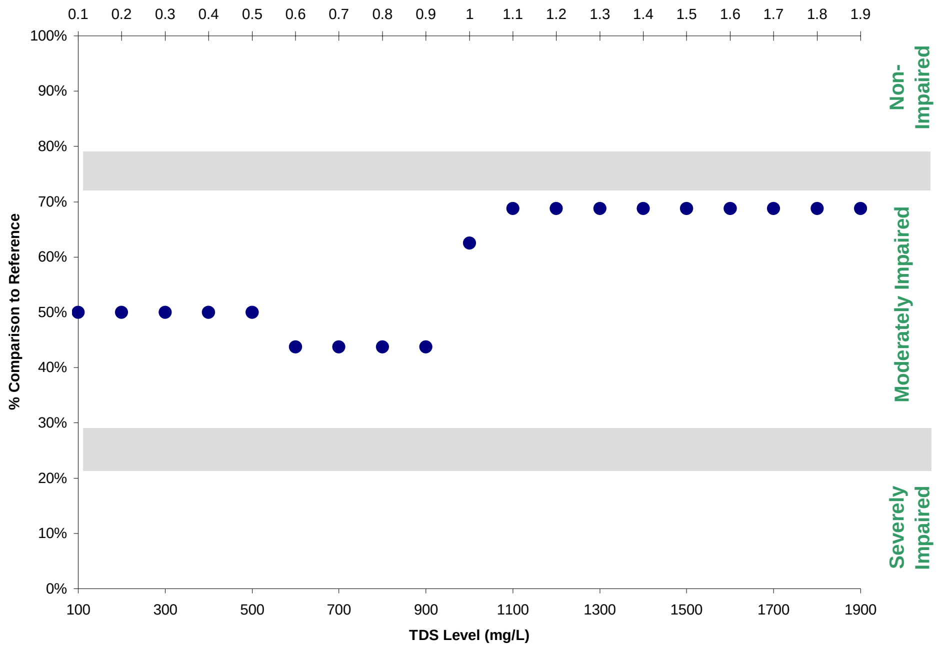


**Figure 5.9 Bioassessment response to changes in TDS level (mg/L)**

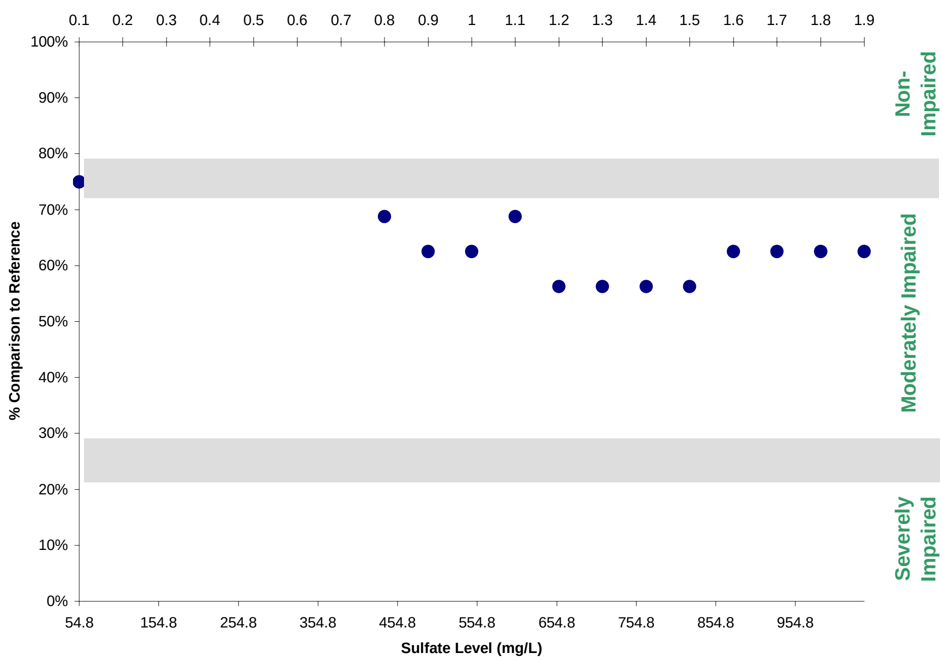


**Figure 5.10 Bioassessment response to changes in Sulfate level (mg/L)**

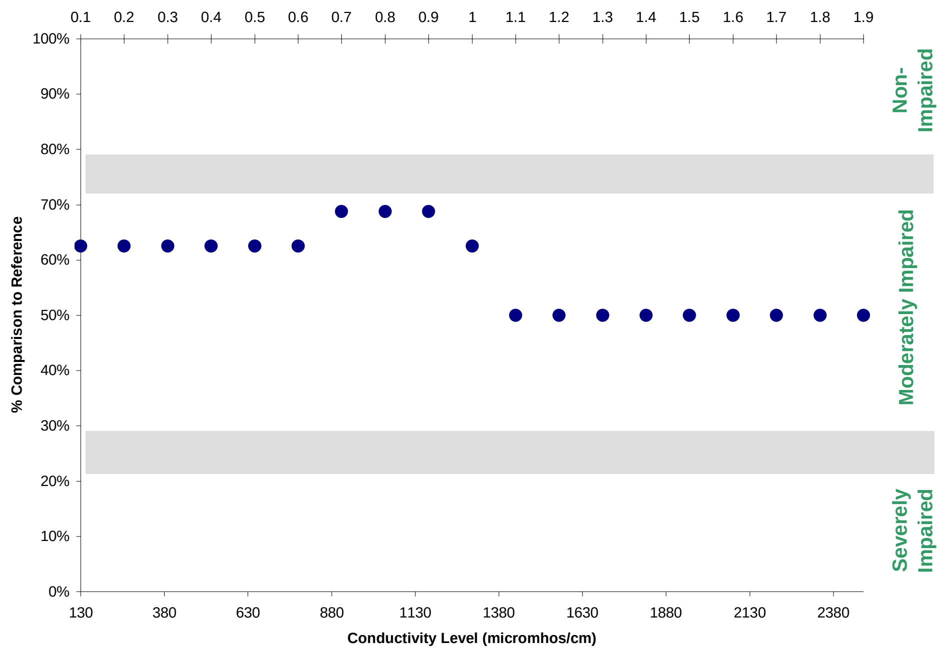


**Figure 5.11 Bioassessment response to changes in Conductivity level (micromhos/cm)**

## *5.2 Incorporation of a Margin of Safety*

A margin of safety (MOS) can be implicit or explicit. It is incorporated into a TMDL in an effort to account for scientific errors inherent to the TMDL development process, measurement uncertainty in model parameters, and to account for trends which might prevent the water quality goal, as targeted by the TMDL, from being achieved. Scientific errors arise from our inability to fully describe mathematically the processes and mechanisms by which pollutants are delivered to the stream. Model calibration is an attempt to address these errors through adjusting model parameters until a suitable fit to observed data is achieved. Measurement uncertainty also introduces errors in the model calibration, because model parameters that are adjusted to non-representative conditions result in model simulations being biased either low or high. For example, observed data used for model calibration were collected for monitoring permit compliance. As a result, flow values were estimated rather than measured. Calibration to estimated data introduces modeling uncertainty. To ensure a pollutant reduction, long-term trends in pollutant sources must be considered in load allocations. For instance, if loads from monitored AMD sites are increasing, then a larger MOS might be appropriate to account for the increase.

The MOS is a subjective value, representing a balance between complete certainty of reaching the in-stream standard and not meeting the standard. The MOS was entered implicitly through choice of the endpoint. The endpoint was set at an average bioassessment score of 85% (Section . 2.1) representing the average bioassessment score for reference stations assessed in the coalfield region of Virginia. This score exceeds the non-impaired criterion of 79% used during the original assessment, and far exceeds

Virginia's current bioassessment score (i.e. the slightly impaired criterion of 51%) that would result in a 303(d) listing.

## 5.3 Scenario Development

Allocation scenarios were modeled using HSPF and the bioassessment model. Allocations were developed for three stations on Black Creek; the outlet of subwatershed 5 in upper Black Creek, the outlet of subwatershed 11 in lower Black Creek, and the outlet of subwatershed 21 representing the outlet of the entire watershed. Inputs from upstream subwatersheds were based on allocated loads for those areas. Existing conditions were adjusted for these stations until the water quality standard was attained (Table 5.1). The endpoint for the standard was an average bioassessment of 85%. Thirty-day average stressor inputs to the bioassessment model were used to represent chronic conditions. The development of the allocation scenario was an iterative process that required numerous runs with each followed by an assessment of source reduction against the water quality target. Additional reductions were made until the target was achieved.

### 5.3.1 Wasteload Allocations

One permitted point source was modeled during allocation runs, the direct mine discharge from mine permit #1201542. Other permitted point sources currently existing in the watershed were considered to be accounted for in the load allocation as they are temporary best management practices installed to control NPS pollution resulting from current surface mining operations. Upon completion of mining operations, these ponds will likely be removed. It is anticipated that the nonpoint load will be reduced from that of the modeled condition due to reclamation requirements established by SMCRA. As such, the allocations developed for Black Creek represent required post-reclamation conditions. The point source was modeled at maximum permitted 30-day average concentrations (i.e. 35 mg/L TSS, 3.0 mg/L Total Fe, and 2.0 mg/L Total Mn), and the median recorded flow rate of 50 gpm. The manganese contribution from this point source apeared to be a limitting factor during low flow conditions, resulting in a load reduction of 80% being required.

### 5.3.2 Load Allocations

Based on the sensitivity analyses for Black Creek, Total Mn was targeted as the first pollutant to reduce. Multiple reductions were assessed, with the highest reduction attempted (90%) in subwatersheds 2-11 resulting in significant increases in the average bioassessment (Table 5.1, Scenario B).

Conductivity was targeted next, with a 70% reduction in subwatersheds 2-11 resulting in the average bioassessment being above 75% for all three stations (Table 5.1 Scenario B). An acceptable allocation was achieved for the outlet of subwatershed 5 with scenario C, including reductions in Total Mn and specific conductivity, and an increase in Alkalinity. The water quality endpoint of an 85% bioassessment score could not be reached for subwatershed 11 without reducing the Total Mn load from the direct mine discharge (mine permit #1201542). This 80% load reduction was calculated relative to the maximum permitted average daily load. Upon meeting the reductions needed for subwatershed 11, subwatershed 21 was well within the stated water quality goal (Table

5.1 Scenario D). An example of time-series output from the bioassessment model is shown in Figure 5.12 and a box and whisker plot showing all three stations under allocation conditions is shown in Figure 5.13. Six additional allocation scenarios that satisfy the endpoint requirements were identified and are presented in Table 5.2. Scenario 1 was chosen from among the seven working scenarios based on the preferences of a TMDL workgroup made up of state agency representatives and the contractor. The resulting TMDL is presented in Table 5.3.

**Table 5.1 Average bioassessment score for various allocation scenarios for Black Creek impairment.**

| | Scenario Description[1] | Subwatershed 5 | Subwatershed 11 | Subwatershed 21 |
|---|---|---|---|---|
| **Existing conditions** | | 49% | 56% | 68% |
| **Scenario A:** | 90% of Mn in subwatersheds 2-11 | 58% | 57% | 73% |
| **Scenario B:** | 90% of Mn in subwatersheds 2-11<br>70% conductivity in subwatersheds 2-11 | 76% | 78% | 91% |
| **Scenario C:** | 93% of Mn in subwatersheds 2-5<br>63% conductivity in subwatersheds 2-5<br>79% increase of alkalinity in subwatersheds 2-5 | 86% | 65% | 73% |
| **Scenario D:** | Scenario C plus<br>88% of Mn in subwatersheds 6-11<br>66% conductivity in subwatersheds 6-11<br>49% increase of alkalinity in subwatersheds 6-11<br>80% of Mn in permit 1201542 | 86% | 85% | 93% |

[1] Scenarios express reductions in stressors unless specified otherwise

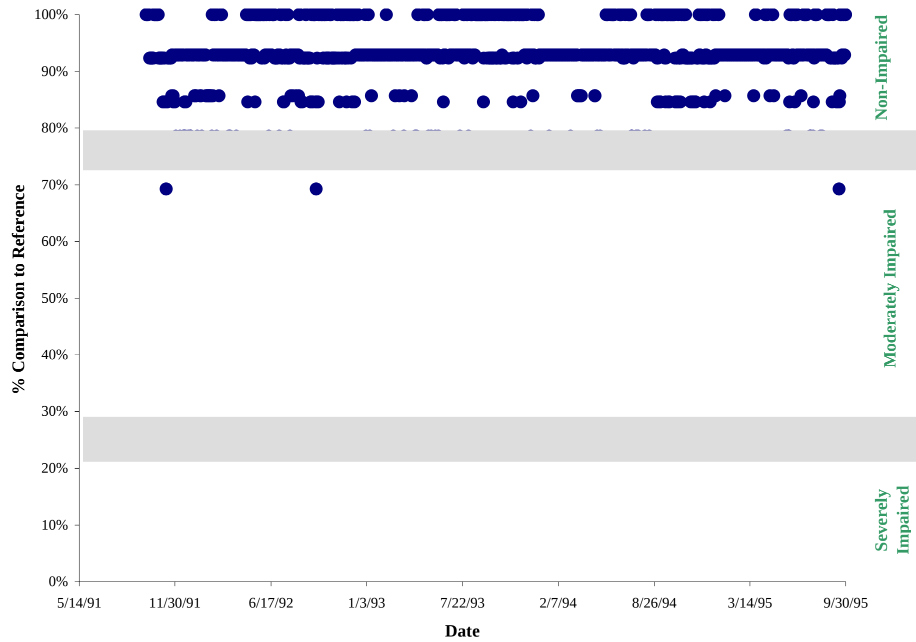


**Figure 5.12 Allocation conditions at Reach 21 (i.e. outlet of Black Creek).**

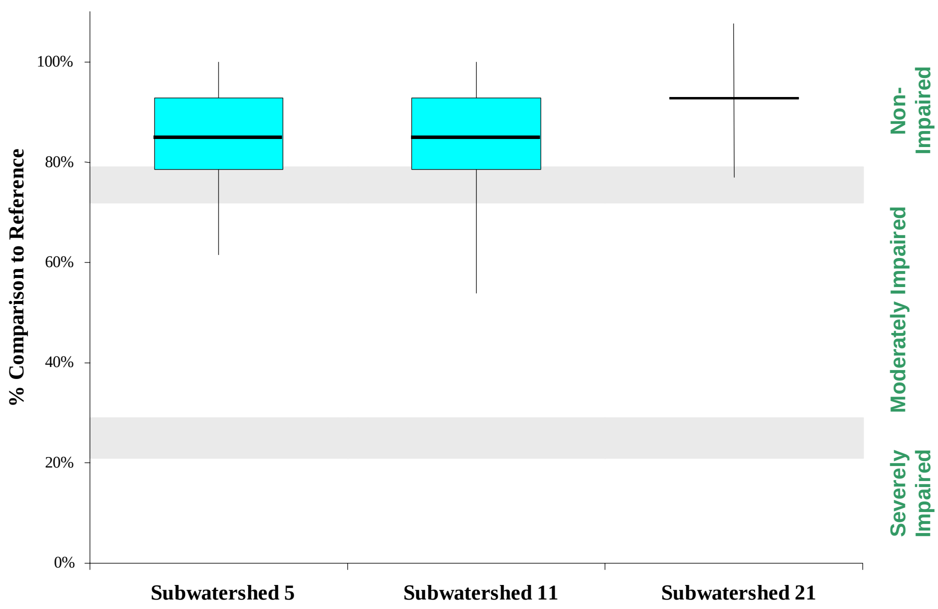


**Figure 5.13 Allocation conditions at 3 stations in the Black Creek watershed.**

**Table 5.2 Seven allocation scenarios developed to address Black Creek's general quality impairment.**

| | | Constituent Load Reductions Under Scenario: | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Constituent** | **Source** | **1** | **2** | **3** | **4** | **5** | **6** | **7** |
| **Total Mn** | SW 2-5 [1] | ***92%*** | 90% | 80% | 80% | 90% | 90% | 90% |
| | SW 6-11 | ***88%*** | 76% | 82% | 59% | 68% | 57% | 85% |
| | SW 12-21 | **–** [2] | – | – | – | – | – | – |
| | NPDES 0081256 | ***80%*** | 90% | 80% | 80% | 75% | 80% | 85% |
| **Total Fe** | SW 2-5 | **–** | – | – | – | 34% | – | – |
| | SW 6-11 | **–** | – | – | – | – | – | 85% |
| | SW 12-21 | **–** | – | – | – | – | – | – |
| | NPDES 0081256 | **–** | – | – | – | 90% | – | 85% |
| **Alkalinity** | SW 2-5 | ***+79%*** [3] | +180% | +172% | +148% | +172% | +150% | +150% |
| | SW 6-11 | ***+48%*** | +60% | +95% | +95% | +81% | +74% | +101% |
| | SW 12-21 | **–** | – | – | – | – | – | – |
| **TSS** | SW 2-5 | **–** | 57% | 57% | 47% | – | 32% | 32% |
| | SW 6-11 | **–** | 19% | – | 12% | – | 8% | 8% |
| | SW 12-21 | **–** | – | – | – | – | – | – |
| **Sulfate** | SW 2-5 | **–** | 30% | 30% | – | 30% | 30% | 30% |
| | SW 6-11 | **–** | 48% | 30% | – | 24% | 30% | 0% |
| | SW 12-21 | **–** | – | – | – | – | – | – |
| **Conductivity** | SW 2-5 | ***63%*** | 50% | 50% | 60% | 66% | 50% | 50% |
| | SW 6-11 | ***66%*** | 51% | 49% | 59% | 53% | 49% | 40% |
| | SW 12-21 | **–** | – | – | – | – | – | – |

[1] "SW #-#" indicates nonpoint sources from the specified subwatersheds.
[2] No reduction is indicated by "–".
[3] All percentages indicate load reductions unless preceded by "+".

**Table 5.3 TMDL allocations chosen for the Black Creek general quality impairment.**

| | Total Mn (kg/year) | Conductivity (µMho-L/cm-year) | Alkalinity ($kgCaCO_3$/year) |
|---|---|---|---|
| ***Waste Load Allocation*** [1] | ***2,127*** | ***N/A*** | ***N/A*** |
| NPDES 0081542 | 40 | N/A | N/A |
| Transient Waste Load [2] | | | |
| NPDES 0081576 | 149 | N/A | N/A |
| NPDES 0081576 | 530 | N/A | N/A |
| NPDES 0081576 | 630 | N/A | N/A |
| NPDES 0081576 | 179 | N/A | N/A |
| NPDES 0081576 | 398 | N/A | N/A |
| NPDES 0081542 | 201 | N/A | N/A |
| ***Load Allocation*** | ***1,599*** | ***5,865,550*** | ***842,997*** |
| Subwatershed 1 | 64 | 288,913 | 49,674 |
| Subwatershed 2-5 | 421 | 1,184,506 | 155,231 |
| Subwatershed 6-11 | 927 | 2,324,451 | 517,925 |
| Subwatershed 12-21 | 187 | 2,067,680 | 120,167 |
| **TMDL** | **3,726** | **5,865,550** | **842,997** |

[1] These discharges are only permitted for the control of pH, total suspended solids, total manganese, and total iron. Other constituent loads must be considered as part of the load allocation.

[2] The transient waste load represents the waste load from runoff-controlling BMPs (i.e. ponds) that are likely to be removed upon completion of current mining operations.

### *5.4 Implementation*

The goal of this TMDL was to establish a three-step path that will lead to expeditious attainment of water quality standards. The first step in this process was to develop a TMDL allocation that will lead to the attainment of water quality standards.. The second step is to develop a TMDL implementation plan, and the final step will be to implement the TMDL and attain water quality standards.

Section 303(d) of the Clean Water Act (CWA) and current EPA regulations do not require the development of implementation strategies. However, Virginia's 1997 Water Quality Monitoring, Information and Restoration Act (WQ MIRA) directs VADEQ in section 62.1-44.19.7 to "*develop and implement a plan to achieve fully supporting status for impaired waters*". The Act also establishes that the implementation plan shall include the date of expected achievement of water quality objectives, measurable goals, corrective actions necessary and the associated cost, benefits and environmental impact of addressing the impairments. EPA outlines the minimum elements of an approvable implementation plan in its 1999 "*Guidance for Water Quality-Based Decisions: The TMDL Process*". The listed elements include implementation actions/management measures, time line, legal or regulatory controls, time required to attain water quality standards, monitoring plan and milestones for attaining water quality standards.

During development of the Black Creek general quality implementation plan, the state reserves the right to select one of the other EPA-approved scenarios presented in the Black Creek general quality TMDL report. After public input, if one of the other EPA-approved scenarios proves to be better for the attainment of water quality standards than scenario #1, Virginia may consider changing the allocation scenario. The allocation section of this Black Creek general quality TMDL report will be revised to include the new selection, and EPA will be notified of the change by letter. If a scenario not identified in the TMDL report is chosen during implementation plan development, then a revised TMDL would be submitted to EPA for review and approval. Public input would be required in this situation as well.

Since this TMDL consists primarily of NPS load allocations originating from mining activities, VADMME will have the lead responsibility for the development of the implementation plan. VADMME and VADEQ will work closely with watershed stakeholders, interested state agencies, and support groups to develop an acceptable implementation plan that will result in meeting the water quality target. Once developed, VADEQ intends to incorporate the TMDL implementation plan into the Clinch/Powell River Water Quality Management Plan (WQMP), in accordance with the CWA's Section 303(e). In response to a Memorandum of Understanding (MOU) between EPA and VADEQ, VADEQ also submitted a draft Continuous Planning Process to EPA in which VADEQ commits to regularly updating the WQMPs. Thus, the WQMPs will be, among other things, the repository for all TMDLs and TMDL implementation plans developed within a river basin.

Funding sources for implementations will be identified. Over 71,000 acres of land in Virginia have been affected by coal mining. It is estimated that it would take approximately 55 years at the present rate of funding and reclamation construction to reclaim just the high priority Abandoned Mine Land (AML) sites. In addition, it would cost more than $300 million to reclaim the AML sites causing environmental degradation. One potential source of funding for TMDL implementation is Section 319 of the Clean Water Act. In response to the federal Clean Water Action Plan, Virginia developed a Unified Watershed Assessment that identifies watershed priorities. Watershed restoration activities, such as TMDL implementation, within these priority watersheds are eligible for Section 319 funding. Increases in Section 319 funding in future years will be targeted towards TMDL implementation and watershed restoration. Additional funding sources may be available through the U. S. Office of Surface Mining.

### 5.4.1 Stage I Implementation Goal

Implementation of best management practices (BMPs) in the watersheds will occur in stages. The benefit of staged implementation is that it provides a mechanism for developing public support and for evaluating the adequacy of the TMDL in achieving the water quality standard. The first stage was initiated with the installation of two constructed wetlands located on the main stem of Black Creek. Installation of the wetlands was completed in 2001. VADMME is currently evaluating the efficacy of these practices in improving water quality within Black Creek.

It is anticipated that the AML and AMDs will be initial targets of implementation. One way to accelerate reclamation of AML is through remining. The Virginia Department of Mines, Minerals and Energy's Division of Mined Land Reclamation, The Nature Conservancy, Virginia Tech/Powell River Project, and U. S. Office of Surface Mining combined resources to develop proposals for incentives that will promote economically viable, environmentally beneficial remining operations that reclaim AML sites. Initial meetings led to the development of a Remining Ad Hoc Work Group that includes representatives from industry, other governmental agencies, special interest groups, and citizens of Southwest Virginia. The Ad Hoc Group has identified existing incentives and continues to propose new ones.

One of the most important existing incentives is the alternative effluent limitations assigned to remining operations with pre-existing pollutant discharges. These regulations (known as the Rahall Amendment) were the result of a 1987 revision to the Federal Clean Water Act (CWA). Alternate effluent discharge limits are allowed in coal mining areas with pre-existing effluent problems. Operators document effluent conditions prior to remining. Upon completion of the remining operation and prior to reclamation bond and permit release, the operator would need to demonstrate that the pollution load from the site is equal to or less than premining pollution load. Because the remining revisions were promulgated after the original TMDL provisions of the CWA, pollution load allocations and implementation plans should be designed to preserve the incentives implicit in the Rahall Amendment. There are three Rahall dicharges within the Black Creek Watershed (Table 5.4). When completed, the mining activities associated with these Rahall permits are expected to eliminate many of the pollutant sources (e.g. mine seeps) that are causing the current problem. The first stage of implementation will target source areas not addressed by the Rahall permits.

**Table 5.4 Permitted loads from Rahall discharges in Black Creek.**

| Permitted Discharge | Monthly Average (lbs/day) | | | Daily Maximum (lbs/day) | | |
|---|---|---|---|---|---|---|
| | Acidity | Iron | Manganese | Acidity | Iron | Manganese |
| Rahall 1 | 81 | 0.5 | 0.9 | 397 | 8.5 | 4.1 |
| Rahall 2 | 136 | 0.74 | 3.2 | 554 | 14.5 | 34.3 |
| Rahall 3 | 50 | 1.8 | 3.8 | 200 | 13.7 | 11 |
| Total | 267 | 3.04 | 7.9 | 1151 | 36.7 | 49.4 |

Through the remining process in Black Creek, combined with the Department of Mines, Minerals, and Energy’s wetland enhancement project, there exist reasonable assurance that the pollution load reductions proposed in the TMDL can be achieved. Some of the best supporting data on pollution load reductions resulting from successful remining operations is included with EPA’s remining Best Management Practices (BMPs) document – in particular Pennsylvania’s remining database.

In 1998, the Pennsylvania Department of Environmental Protection (PADEP) developed a remining database to determine the success of Pennsylvania's remining program. The database specifically quantifies the extent to which bituminous coal remining sites have reduced pollution loads from the pre-existing conditions. Evaluations of the data were made by comparing pre-mining and post-mining loads at individual discharges for several parameters. The results are included in a report - broken down by stressor or pollutant. The database includes water quality information from more than 200 remining sites. BMPs used at the remining sites were common to surface mining activities throughout the Appalachian region and included daylighting deep mines, regrading, revegetation, and alkaline soil addition. The BMPs did not include chemical treatment, constructed wetlands, or long term treatment mechanisms.

The PADEP results document that for those sites that reduced the level of manganese, the average load reduction was 70%. For every site in the study, PADEP summarized the load reduction for acidity and found that it was 61%. Similar load reductions were measured for the other pollutants of interest. When the observed pollution reductions associated with the re-mining process are compared to the modeled load reductions needed to improve Black Creek, the recommended reductions for the stream appear attainable.

## 6. PUBLIC PARTICIPATION

A key element in the development of a TMDL is public participation. During the course of developing the TMDL for Black Creek, three meetings were held (Table 6.1). The first public meeting on June 5, 2001 was held at the Big Stone Gap Offices of DMME. An introduction of the agencies involved, an overview of the TMDL process and the specific approach to developing the Black Creek TMDL were presented at the first public meeting. The second public meeting on January 29, 2002 was a combination TMDL meeting on Black Creek and Dumps Creek held at the Clinch Valley Chapter, Order of the Eastern Star, Dinsmore Hall, St. Paul, Virginia. The second public meeting was held at both 3:00 pm and 6:00 pm to allow for maximum attendance of both industry representatives and the public at large. Details of the hydrologic calibration, pollutant sources, water quality modeling and initial results from the biometrics model simulations were presented during this meeting. During the third and final meeting held on April 15, 2002 at the Big Stone Gap Offices of DMME, results of the water quality model, biometrics models and load allocations were presented. All meetings were advertised in the *Virginia Register*. Before the final meeting, stakeholders who had registered at previous meetings were telephoned. Presentation materials were distributed at each meeting.

**Table 6.1 Public participation in the TMDL development for the Black Creek Watershed.**

| Date | Location | Attendance [1] | Format |
|---|---|---|---|
| 6/5/01 | Big Stone Gap Offices of DMME | 18 (13 project personnel) | Open to public at large |
| 10/2/01 | Clinch Valley Chapter, Order of the Eastern Star, Dinsmore Hall St. Paul, Virginia | 17 (10 project personnel) | Open to public at large |
| 4/15/02 | Big Stone Gap Offices of DMME | 16 (8 project personnel) | Open to public at large |

[1] The number of attendants is estimated from sign up sheets provided at each meeting. These numbers are known to under estimate the actual attendance.

# APPENDIX: A

# VIRGINIA'S REGRESSION METHOD FOR BENTHIC TMDLS

# Virginia's Regression Method for Benthic TMDLs

## 1. Background

In developing a TMDL for Black Creek, Wise County, VA, a relationship between the impairment (i.e. benthic macroinvertebrates) and the stressor(s) causing the impairment (e.g. iron flocculent) had to be defined either explicitly or implicitly. Hypotheses formulated during the initial phase of this effort speculate that metal flocculants act "physically like fine sediment, filling habitat spaces and interfering with respiration and feeding of the benthic invertebrates" (Virginia Department of Mines, Minerals and Energy, VADMME, special study 1999). Further speculation is that the impairment was not the result of metal toxicity. In contrast, a toxicity study specific to the Black Creek drainage conducted by Dr. Don Cherry with Virginia Tech "indicates toxicity within the creek itself" was of concern. Regardless of these statements, the fact is that neither study developed a quantifiable link between the impairment and the pollutant(s) causing the problem. In analyzing observed data to identify stressors, USEPA (2000) states that the use of "regression techniques to quantify the relationships between variables [is] encouraged."

Developing the link or relationship between stressors and benthic health is a key component of the Black Creek TMDL and may produce a relationship that is applicable to other coalfield impairments. In order to accomplish this task, biological, chemical and physical data has been compiled from the Black Creek drainage, as well as, from similar areas in southwest Virginia and eastern Kentucky (Figure 1.). Data has been collected from studies conducted by VA Tech (i.e. Cherry's work), VADEQ, VADMME and Appalachian Technology Services (ATS). The combined data set consists of 155 records (Attachment A: Table 1).

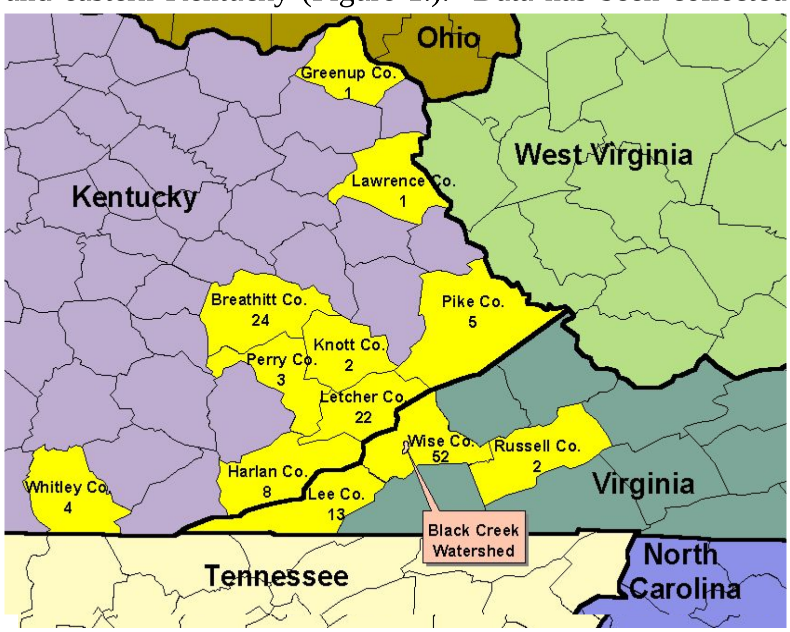


**Figure 1. Locations (highlighted in yellow) of data sources utilized to develop the Black**

Multi-parameter statistical analysis was performed on the compiled data set, to identify the primary pollutant(s) causing the impairments and to establish a mathematical relationship between pollutant levels and the benthic community. Statistical analysis was conducted using each of seven individual metrics as the independent variable (the eighth metric, Community Loss Index, is calculated from Taxa Richness). The resulting parameter estimates for the Black Creek model are given in Attachment B.

## 2. Technical Description of Proposed Method

### *1. What waters will be covered?*

The regression model developed for use in the Black Creek TMDL should be applicable to benthic-impaired waters throughout the coalfields of Appalachia. In applying the model to impairments other than Black Creek, the first step should be to compare the monitored bioassessment results to results obtained by inputting monitored stressor data to the regression model. If results are inconsistent, then additional stressors should be considered for inclusion in the model.

While this specific regression model is being developed for application to coalfield watersheds, a similar approach, evaluating appropriate stressors, could be used in primarily agricultural or urban watersheds.

### *2. What are the details of the method?*

The proposed method is comprised of two functional models (Figure 2). The first model (water quality model) describes the fate and transport of the stressors delivered to and processed through the impaired stream segment. This model is common to all TMDLs and its complexity is determined by the critical conditions and the fate and transport mechanisms that define the critical conditions. This portion of the method is illustrated

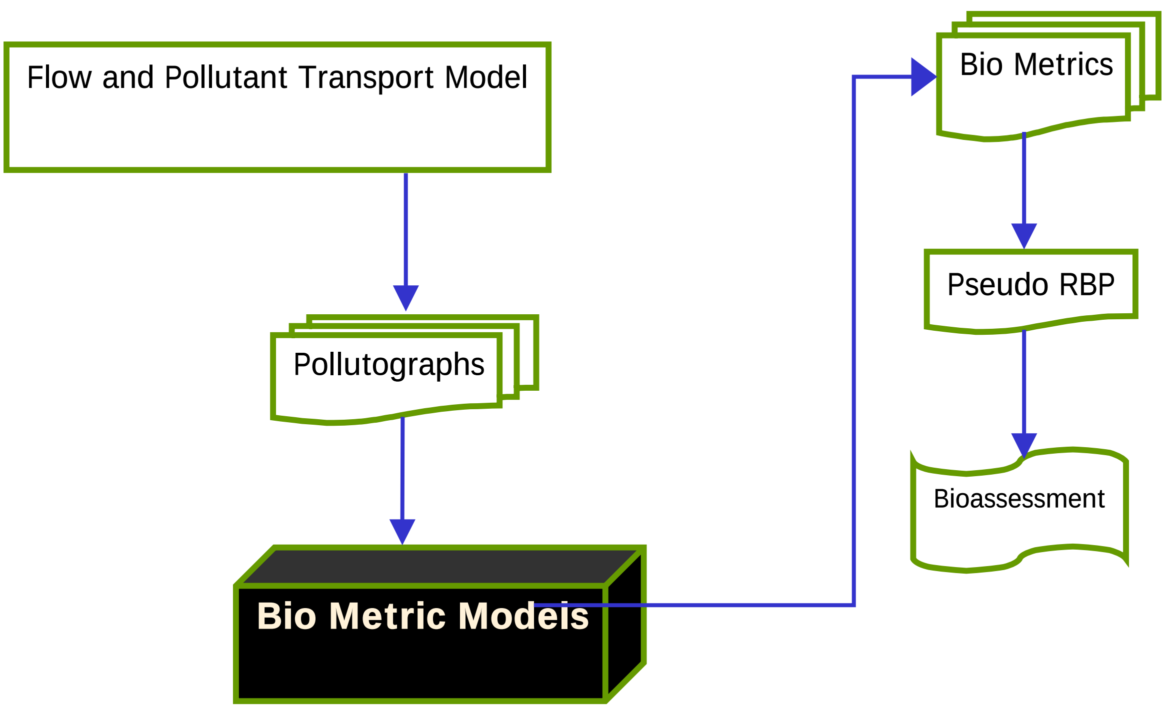


**Figure 2. The proposed conceptual model for developing TMDLs using the Regression Method for Benthic TMDLs.**

in Figure 2 as the flow and pollutant transport model, which produces the pollutographs. The second functional model is the bioassessment model. It is comprised of those elements that model the benthic macroinvertebrate health, as illustrated in Figure 2, and consists of the blocks from the multi-parameter analysis to the bioassessment block. This model mimics the real world execution of Virginia's general standard in that it is comprised of the biometrics and the reference station that are incorporated in Virginia's assessment of the impairment.

At the core of the bioassessment model is the multi-parameter analysis, which describes the relationship of the various stressors to individual RBP metrics. Using statistical regression techniques (e.g. forward, backwards, and stepwise regression), mathematical relationships between the potential stressors and each metric are determined. The stressors included in this analysis are considered common to activities (e.g. mining) within the impairment's watershed. For the Black Creek case study, the potential stressors are common to active and abandoned surface and deep coal mining activities (e.g. acid mine drainage, soil erosion, etc.) in Appalachian coalfields. These stressors are regressed against the eight metrics (e.g. taxa richness and percent dominant family) that comprise Virginia's bioassessment score. Table 1 lists the biometrics that comprises Virginia's bioasessment score and their relationship to the aquatic health (e.g. with increasing Taxa Richness the benthic health is expected to increase). For the case study, the stressors incorporated into the analysis are common across our coalfield region; therefore, the resulting relationships should be widely applicable to similar impairments in Virginia.

**Table 1. Virginia's Biometrics.**

| Biometric | Benthic Health |
|---|---|
| Taxa Richness | ↑ |
| Modified Family Biotic Index | ↓ |
| Scraper to Filtering Collector Ratio | ↑ |
| EPT / Chiromnomid Ratio | ↑ |
| % Contribution of Dominant Family | ↓ |
| EPT Index | ↑ |
| Community Loss Index | ↓ |
| Shredder to Total Ratio | ↑ |

Biometrics for each record were recalculated from raw data, as needed, to ensure that all metrics were calculated at the family level. Upon standardizing the biometric data, all records in the dataset were consistent in terms of biometric data; however, records did not each contain the same water quality parameters. Because of this, the regression analysis followed the following process:

1) Stepwise regression using full set of basic parameters (i.e. linear terms). Criterion for removal/addition of terms was $\alpha$=0.25.
2) Regression recalculated with identified parameters including additional records as possible (e.g. if discharge was not identified as an important parameter in the first step, additional records that did not include discharge data could be analyzed in this step).
3) Stepwise regression including identified parameters and interaction terms.
4) Repeat step 2.

5) Stepwise regression including identified parameters and natural log of basic terms.
6) Repeat step 2.
7) Stepwise regression including identified parameters and square of basic terms.
8) Repeat step 2.

For each stepwise regression performed; forward, backward, and mixed regression models were developed and the model that produced the largest $R^2$ value was retained. In order to avoid over fitting the model, the number of parameters was not allowed to exceed (n-20)/2, where n is the number of records included in the analysis. The process was terminated when this limit was reached or all of the parameters, including the non-linear permutations discussed above, had been evaluated.

The result of this task is a statistical model that defines the relationship between pollutant levels (stressors) and the level of impairment. Results from hydrologic/water quality modeling will be linked into the statistical model to simulate the temporal impact to each biometric.

As illustrated in Figure 3, the pollutographs from the water quality model are coupled with the relationships determined through the multi-parameter analysis to produce a modeled metric score. These modeled metrics are processed in the same manner as measured metrics (Figure 4.) - i.e. compared with (modeled) metrics for a reference station - resulting in a modeled bioassessment (e.g. non impaired, moderately impaired) for a targeted site.

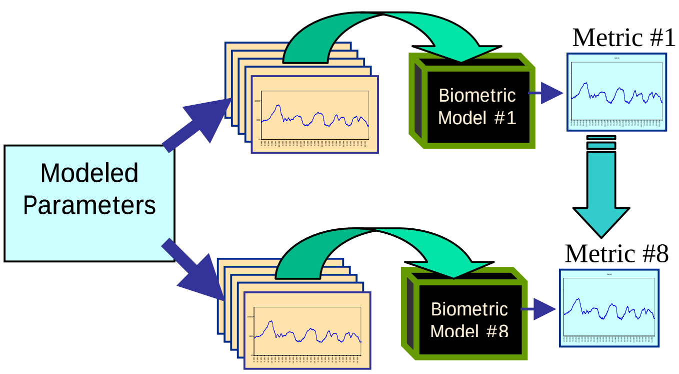


**Figure 3. Conceptual application of the linkage between the water quality and biometric models.**

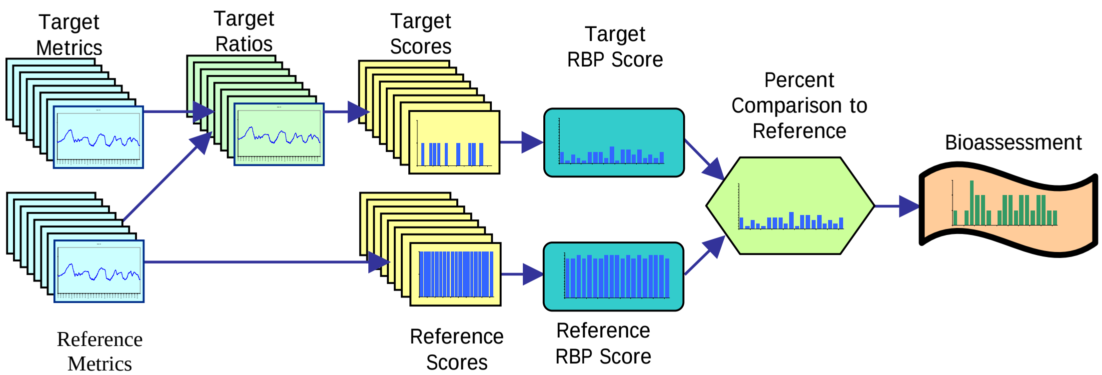


**Figure 4. Bioassessment Protocol**

*3. What are the data requirements?*

In developing the regression model relating stressors to benthic health, instream chemical and physical data must be paired with instream biological data. Data from the state's ambient water quality-monitoring program, supplemented with data collected in support of permit requirements will be used in determining these relationships.

With regard to a specific impairment's TMDL, sufficient data for modeling the pertinent stressors under critical conditions are required.

*4. What are the advantages of the method?*

The key advantage of this methodology is that it produces an objective link between the causative agents and narrative standard. In doing so, the interactions of the various causative agents are considered and potentially result in various remediation scenarios. This provides an opportunity for the public to select the most appropriate implementation scenario.

Through the statistical process of developing the biometric models, an assessment of the level of uncertainty can be established. In contrast, other methods for establishing the endpoints (e.g. reference watershed approach) have levels of uncertainty that are not readily quantifiable.

The bioassessment model developed for the Black Creek case study incorporated regional data and is expected to be broadly applicable in the coalfields of Virginia. The broad application of this model is expected to eliminate the need for similar analysis in future coalfield TMDLs, thereby reducing the overall cost of these TMDLs. With detailed chemical and physical characterization of water quality, simplified water quality modeling (as compared to HSPF) may be appropriate, further reducing the cost of these TMDLs. The simplified methods are especially appropriate for those situations where the sources of the pollutant loading are not significantly affected by landuse activities, and/or seasonal weather patterns.

*5. What are the disadvantages of the method?*

As with all narrative standards the causative agent is not known without some degree of uncertainty. Although this method allows for some measurement of the uncertainty, the uncertainty exists nonetheless. The level of uncertainty would be expected to reduce as additional data are collected through ongoing programs and incorporated into the biometric models. These ongoing monitoring programs would be based on standard protocols designed to support the improvement of statistically based biometric models. For example, VADEQ has initiated the collocation and timing of chemical (i.e. ambient water quality) and biological monitoring stations.

It is worth noting that a leading environmental statistian, Dr. Eric Smith, of Virginia Tech's Department of Statistics has reviewed this method for developing the Black Creek TMDL. His preliminary review stated, "Overall, I am supportive of the approach. I think the approach is superior to other TMDL approaches that do not include data directly." Furthermore, enviromental chemist, Dr. David Johnson, of Ferrum College, states that in spite of uncertainties due to the limited data available, this method is superior to approaches currently implemented within the state.

## 3. Evaluation of Method in terms of regulatory conditions pursuant to 40 CFR §130

*1. Using the regression method, are the TMDLs designed to implement applicable water quality standards?*

The applicable water quality standard is Virginia's General Standard, which is implemented through monitoring of benthic macroinvertebrate communities via the Rapid Bioassessment Protocol (RBP). Using the Regression Method for Benthic TMDLs, a relationship between potential stressors and individual metrics that comprise the RBP is developed. These modeled metrics are combined, following the RBP, into a bioassessment score (e.g. moderately impaired). In doing so, the state standard is directly addressed. For example, Figure 5 shows the simulated existing conditions (i.e. bioassessment scores) generated from the linkage of the water quality model and the bioassessment model for Black Creek during water year 1996. The observed bioassessment for this station was moderately impaired.

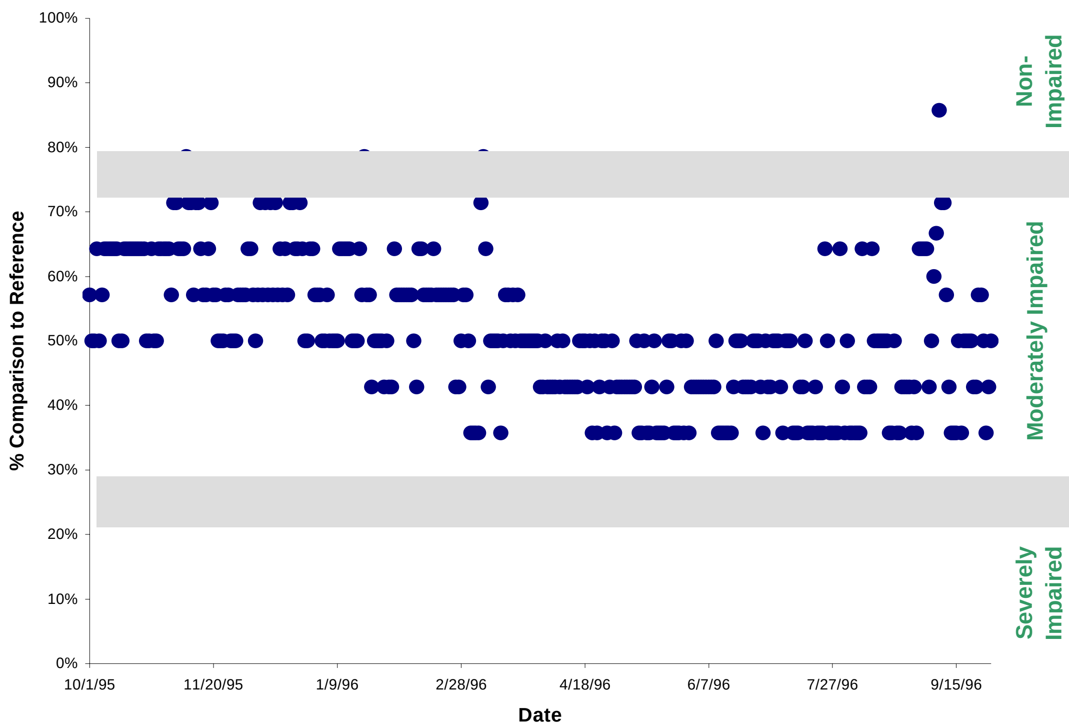


**Figure 5. Black Creek modeled current conditions as expressed by the bioassessment protocol.**

2. *Will the TMDLs contain allowable loading, waste load allocations, and load allocations?*

With a relationship developed between stressors and benthic health, stressors can be modeled using a continuous model that considers climatic, hydrologic and management conditions (e.g. HSPF), and the resulting stressor levels can be used to calculate modeled RBP assessments. Using this approach, current conditions as well as allocation scenarios can be modeled. Reduction of stressor levels will be determined by adjusting the appropriate model parameters until the modeled bioassessment meets state standards (i.e.

non-impaired). Upon identifying a workable scenario for full implementation, allowable loading, waste load allocations, and load allocations will be calculated.

3. *Does the TMDL consider background pollutants?*

Since the Regression Method allows modeling of specific stressors (e.g. total iron and sediment), the TMDLs will consider background pollutants through inclusion in the model. Multiple pollutants will be modeled and background levels of each will be included in the model through the most appropriate method (e.g. groundwater contributions, or an additional direct load).

In addition, by design the bioassessment protocol compares the targeted water quality station to a non-impaired reference station. The reference station, by default, considers background levels of the various stressors.

4. *Does the TMDL consider critical environmental conditions?*

A modeling period will be chosen to address the full range of climatic conditions that can be expected for the watershed in question. The use of a continuous model that considers climatic, hydrologic and management conditions allows for modeling all potentially critical environmental conditions that result from combinations of climate and management situations.

5. *Do TMDLs consider seasonal environment variations?*

As stated previously, a continuous model that considers climatic, hydrologic and management conditions will be incorporated into the TMDL development process. This will allow for seasonal variations in climatic conditions, as well as, seasonal changes in land-use management. For example, Figure 6 depicts the results from a five-year model simulation for flow and total dissolved solids within Black Creek. This five year period represents typical climatic conditions observed in the Black Creek watershed. As

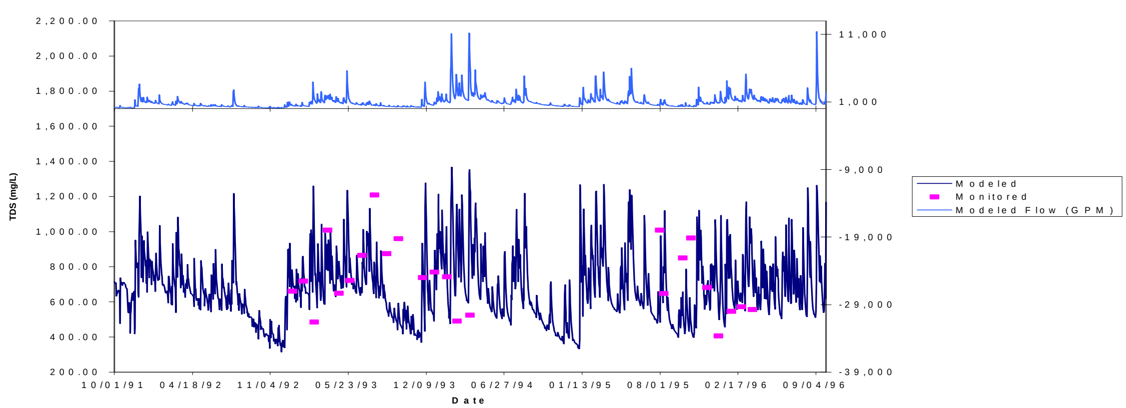


**Figure 6. Predicted total dissolved solids and flow for Black Creek.**

shown in Figure 5, the seasonal variation is reflected in the bioassessment simulations.

6. *Do TMDLs include margin of safety?*

Once an acceptable combination of stressor levels is determined, either an implicit or explicit margin of safety will be applied to the level determined for each stressor. The required allocation reductions will then be based on meeting this goal.

7. *Will TMDLs be subject to public participation?*

Fundamental to the Commonwealth's TMDL development process is public participation. At a minimum two public meetings are held in the local area of the impairment to describe the water quality condition of the impaired stream, the TMDL development process, and the resulting TMDL allocation reductions. As part of this involvement, the public has an opportunity to review and submit comments on the TMDL.

8. *Is there reasonable assurance that the TMDL can be met?*

The Regression Method for Benthic TMDLs was developed so that multiple allocation scenarios could be evaluated, with consideration for the management requirements of implementation. In being able to model various allocation scenarios and incorporate public input into selecting the most workable solution, the TMDL will be developed in such a way that it has the highest level of assurance possible.

**4. Response to EPA Comments.**

In response to the request for further documentation on several issues associated with the TMDL for Black Creek, supplied by Mr. Peter Gold of Region III, USEPA, the following is provided (This information was submitted to VADMME and VADEQ December of 2001). Mr. Gold's comments are presented in italics, directly quoted from his letter dated September 10, 2001.

Comment number 1 states: *The "reference site" for the Black Creek TMDL seems to already have some impairment based on taxa richness and low EPT richness. There are several unmined watersheds in the Cumberland Mountains portion of West Virginia, which are unimpaired watersheds and are located in a similar eco-region. By using the* *"reference site" described in your presentation, the threshold for demonstrating an impairment would be lowered.*

The reference site for the Black Creek assessment was established during the study conducted by Dr. Donald Cherry of Virginia Tech. As a result of this specific study, Black Creek was listed on Virginia's 303(d) list as being impaired from its confluence with the Powell River upstream to the outlet of Black Creek Lake. It was the stream quality at this site that expressed the state's standard for Black Creek. The selection of an alternate reference site for the purpose of developing the TMDL would in effect change the State's standard as applied to Black Creek and in doing so would be inappropriate.

The reference site used for the Black Creek assessment is in fact comparable to reference sites used throughout the Commonwealth. Specifically, taxa richness at the Black Creek reference site was measured at 11 and 12 on 8/8/95 and 10/8/95, respectively, while taxa richness recorded by VADEQ at reference sites in the coalfield region of Virginia range from 8 to 23. EPTI at the Black Creek reference site was measured at 3 and 5 on 8/8/95 and 10/8/95, respectively, while EPTI recorded by VADEQ at reference sites in the coalfield region of Virginia range from 4 to 13. A cursory survey of the reference site conducted by MapTech and Virginia Department of Conservation and Recreation (VADCR) personnel on June 6, 2001 showed a diverse population of the benthic macroinvertebrate community above Black Creek Lake, including pollutant-intolerant species.

Comment two asks: *Were all of the data used in the regressions collected using the same collection and sampling methods?*

No. Data used for the regression analysis included benthos samples collected using kick sampling and timed visual search methods.

Continuing comment 2: *Were these samples collected in the same season?*

No. Samples were collected at various times during the year.

Comment 2 concludes*: It is necessary to insure that the sampling methods and times are consistent, since changes in collection and sampling methodologies, and seasonality can introduce variability into the data.*

We acknowledge that these differences will introduce variability. In response to this comment, "month of sample collection" was evaluated as a parameter in the biometric models and was found to be a significant factor in EPT Index, Shredder to Total Ratio, and Percent Contribution from Dominant Family. Therefore, month is used as a variable in the regression models for these three benthic metrics.

For the purposes of modeling the biometrics, using sampling methodology, as an independent variable would have questionable utility. The size of the dataset is such that forcing the introduction of these variables into the regression models would be counter productive. Having developed a reasonable model with different sampling methodologies included, a more robust model is available for the TMDL analysis. That is, the results will be independent of sampling methodology.

Comment number three states: *Many of the benthic metrics documented in your presentation are no longer in use because of their innate variability and/or the difficulty associated with their interpretation. The West Virginia Stream Condition Index was developed using the benthic data of WVDEP and has been used in portions of the Cumberland Mountains in West Virginia. This Index used the following metrics: Total Taxa, EPT Taxa, %EPT, %Chironomidea, %2 dominant and HBI. These metrics may be more appropriate for the model.*

Although the metrics mentioned above may be inherently better for doing future assessments they are not appropriate for use in developing the Black Creek TMDL. The study conducted by Dr. Cherry expressed Virginia's standard through the use of the metrics outlined in our presentation. As with the reference site, changing the metrics would in effect change the state's standard and thereby would be inappropriate.

Three of the metrics referenced in the West Virginia study (i.e. Total Taxa, EPT Taxa and HBI) are incorporated into the Virginia bioassessment protocol. Specifically, Taxa Richness, EPT Index and MFBI in Virginia's nomenclature is equivalent to West Virginia's Total Taxa, EPT Taxa and HBI, respectively.

In addition to the comments expressed in Mr. Gold's letter, several concerns were discussed during our September 17th meeting with VADEQ, VADCR and USEPA and the conference call that followed (9/18/01). These concerns focused on the complexity of the resulting regression equations, the potential variability associated with allocations and the limitations of the dataset used for the regression analysis. Inherent to biological systems are complex responses to environmental stressors. These responses are typically nonlinear, for instance, pH can have adverse biological effects at both ends of the scale. The complexity of the regression equations reflects these nonlinearities. The inclusion of stressors comprising the regression equations was determined through appropriate statistical procedures.

With regard to the potential variability associated with allocations, our contention is that there will be no variability in the allocations.  The model will provide a framework for exploring alternative allocation scenarios.  Each scenario will result in explicit end points for each stressor. However, a single scenario will be chosen (with stake holder involvement) for the final TMDL.

To address concerns about the dataset, we identified and requested additional biological/chemical data from EPA.   To date, this data has not been made available.  We have also identified and requested data from the State of Maryland. We expect this data will be forthcoming. In addition, Virginia's Department of Mines, Minerals and Energy has and continues to collect samples specifically to address these concerns.

It is worth noting that Dr. Eric Smith of Virginia Tech's Department of Statistics has reviewed this approach for developing the Black Creek TMDL. His preliminary review stated, "Overall, I am supportive of the approach.  I think the approach is superior to other TMDL approaches that do not include data directly."

## References

USEPA. 2000. Stressor Identification Guidance Document. U.S. Environmental Protection Agency, Office of Water. Washington, D.C. December 2000. EPA 822-B-00-025

**Attachment A:**

**Water quality and biometric data used**

**in developing multi-parameter regression model.**

**Table 1. Coalfield water quality and biometric data used in developing multi-parameter regression model. (Part 1 of 12)**

| Record | Location | Site ID | County | State | Date | Collectors | H2O Lab | Total Zinc | Settable Solids | Hardness | Turbidity |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Craborchard Creek | AS-1 | Lee | VA | 26-Oct-99 | RRK | ATS hand held meters | . | . | . | . |
| 2 | Craborchard Creek | AS-2 | Lee | VA | 26-Oct-99 | RRK | ATS hand held meters | . | . | . | . |
| 3 | Craborchard Creek | AS-3 | Lee | VA | 26-Oct-99 | RRK | ATS hand held meters | . | . | . | . |
| 4 | Craborchard Creek | AS-4 | Lee | VA | 26-Oct-99 | RRK | ATS hand held meters | . | . | . | . |
| 5 | Craborchard Creek | AS-5 | Lee | VA | 26-Oct-99 | RRK | ATS hand held meters | . | . | . | . |
| 6 | Craborchard Creek | AS-6 | Lee | VA | 26-Oct-99 | RRK | ATS hand held meters | . | . | . | . |
| 7 | Craborchard Creek | AS-7 | Lee | VA | 26-Oct-99 | RRK | ATS hand held meters | . | . | . | . |
| 8 | Craborchard Creek | AS-8 | Lee | VA | 26-Oct-99 | RRK | ATS hand held meters | . | . | . | . |
| 9 | Craborchard Creek | AS-9 | Lee | VA | 26-Oct-99 | RRK | ATS hand held meters | . | . | . | . |
| 10 | Craborchard Creek | AS-10 | Lee | VA | 26-Oct-99 | RRK | ATS hand held meters | . | . | . | . |
| 11 | Craborchard Creek | AS-11 | Lee | VA | 26-Oct-99 | RRK | ATS hand held meters | . | . | . | . |
| 12 | Solomon Fork | AS-1 | Pike | KY | 9-May-99 | RRK, TEH | Environmental Monitoring, Inc. | 0.012 | 0.050 | 504 | 35.10 |
| 13 | Solomon Fork | AS-2 | Pike | KY | 9-May-99 | RRK, TEH | Environmental Monitoring, Inc. | 0.013 | 0.050 | 554 | 13.90 |
| 14 | Solomon Fork | AS-3 | Pike | KY | 9-May-99 | RRK, TEH | Environmental Monitoring, Inc. | 0.007 | 0.300 | 492 | 115.00 |
| 15 | Camp Creek | AS-4 | Pike | KY | 9-May-99 | RRK, TEH | Environmental Monitoring, Inc. | 0.059 | 0.600 | 364 | 319.00 |
| 16 | Big Laurel Creek | AS-1 | Harlan | KY | 26-Feb-01 | RRK, TEH | Technical Water Laboratories, Inc. | 0.002 | 0.005 | 50 | 14.70 |
| 17 | Big Laurel Creek | AS-2 | Harlan | KY | 26-Feb-01 | RRK, TEH | Technical Water Laboratories, Inc. | 0.001 | 0.004 | 50 | 11.80 |
| 18 | Horse Fork | AS-3 | Harlan | KY | 26-Feb-01 | RRK, TEH | Technical Water Laboratories, Inc. | 0.003 | 0.006 | 58 | 13.70 |
| 19 | Horse Fork | AS-4 | Harlan | KY | 26-Feb-01 | RRK, TEH | Technical Water Laboratories, Inc. | 0.001 | 0.005 | 54 | 3.80 |
| 20 | Horse Fork | AS-5 | Harlan | KY | 26-Feb-01 | RRK, TEH | Technical Water Laboratories, Inc. | 0.002 | 0.004 | 51 | 3.50 |
| 21 | Poor Fork Cumberland River | AS-1 | Letcher | KY | 14-Nov-98 | RRK | Technical Water Laboratories, Inc. | . | . | . | . |
| 22 | Poor Fork Cumberland River | AS-2 | Letcher | KY | 14-Nov-98 | RRK | Technical Water Laboratories, Inc. | . | . | . | . |
| 23 | Poor Fork Cumberland River | AS-3 | Letcher | KY | 14-Nov-98 | RRK | Technical Water Laboratories, Inc. | . | . | . | . |
| 24 | Roberts Branch | AS-4 | Letcher | KY | 14-Nov-98 | RRK | Technical Water Laboratories, Inc. | . | . | . | . |
| 25 | Roberts Branch | AS-5 | Letcher | KY | 14-Nov-98 | RRK | Technical Water Laboratories, Inc. | . | . | . | . |
| 26 | Caney Creek tributary | AS-1 | Breathitt | KY | 12-Nov-98 | RRK | Technical Water Laboratories, Inc. | . | . | . | . |
| 27 | Caney Creek | AS-2 | Breathitt | KY | 7-Nov-98 | RRK | Technical Water Laboratories, Inc. | . | . | . | . |
| 28 | Big Sourwood Branch | AS-3 | Breathitt | KY | 7-Nov-98 | RRK | Technical Water Laboratories, Inc. | . | . | . | . |
| 29 | Caney Creek | AS-4 | Breathitt | KY | 7-Nov-98 | RRK | Technical Water Laboratories, Inc. | . | . | . | . |
| 30 | Big Laurel Branch | AS-5 | Breathitt | KY | 7-Nov-98 | RRK | Technical Water Laboratories, Inc. | . | . | . | . |
| 31 | Little Caney Creek tributary | AS-6 | Breathitt | KY | 7-Nov-98 | RRK | Technical Water Laboratories, Inc. | . | . | . | . |
| 32 | Little Caney Creek tributary | AS-7 | Breathitt | KY | 12-Nov-98 | RRK | Technical Water Laboratories, Inc. | . | . | . | . |
| 33 | Allan Patton Branch | AS-8 | Breathitt | KY | 7-Nov-98 | RRK | Technical Water Laboratories, Inc. | . | . | . | . |
| 34 | Allan Patton Branch tributary | AS-9 | Breathitt | KY | 7-Nov-98 | RRK | Technical Water Laboratories, Inc. | . | . | . | . |
| 35 | Allan Patton Branch tributary | AS-10 | Breathitt | KY | 7-Nov-98 | RRK | Technical Water Laboratories, Inc. | . | . | . | . |
| 36 | Allan Patton Branch tributary | AS-11 | Breathitt | KY | 7-Nov-98 | RRK | Technical Water Laboratories, Inc. | . | . | . | . |
| 37 | Allan Patton Branch | AS-12 | Breathitt | KY | 12-Nov-98 | RRK | Technical Water Laboratories, Inc. | . | . | . | . |
| 38 | Little Caney Creek | AS-1 | Breathitt | KY | 25-Mar-98 | RRK | Eco-Tech, Inc. hand held meters | . | . | . | 3.00 |
| 39 | Little Caney Creek tributary | AS-2 | Breathitt | KY | 25-Mar-98 | RRK | Eco-Tech, Inc. hand held meters | . | . | . | . |
| 40 | Little Caney Creek | AS-3 | Breathitt | KY | 25-Mar-98 | RRK | Eco-Tech, Inc. hand held meters | . | . | . | 1.00 |
| 41 | Little Caney Creek tributary | AS-4 | Breathitt | KY | 25-Mar-98 | RRK | Eco-Tech, Inc. hand held meters | . | . | . | . |
| 42 | Big Caney Creek | AS-5 | Breathitt | KY | 25-Mar-98 | RRK | Eco-Tech, Inc. hand held meters | . | . | . | . |
| 43 | Quicksand Creek | AS-6 | Breathitt | KY | 25-Mar-98 | RRK | Eco-Tech, Inc. hand held meters | . | . | . | 5.00 |

**Table 1. Coalfield water quality and biometric data used in developing multi-parameter regression model. (Part 2 of 12)**

| Record | Location | Site ID | County | State | Date | Collectors | H2O Lab | Total Zinc | Settable Solids | Hardness | Turbidity |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 44 | Quicksand Creek tributary | AS-7 | Breathitt | KY | 25-Mar-98 | RRK | Eco-Tech, Inc. hand held meters | . | . | . | . |
| 45 | Left Fork Cloverlick Creek | AS-1 | Harlan | KY | 24-May-99 | RRK | Technical Water Laboratories, Inc. | . | . | . | . |
| 46 | Left Fork Cloverlick Creek | AS-2 | Harlan | KY | 24-May-99 | RRK | Technical Water Laboratories, Inc. | . | . | . | . |
| 47 | Left Fork Cloverlick Creek | AS-3 | Harlan | KY | 24-May-99 | RRK | Technical Water Laboratories, Inc. | . | . | . | . |
| 48 | Laurel Creek tributary | AS-1 | Lawrence | KY | 1-Dec-00 | RRK | Technical Water Laboratories, Inc. | . | 0.000 | . | . |
| 49 | Birchfield Creek | AS-1 | Wise | VA | 13-Mar-99 | RRK | N/A | . | . | . | . |
| 50 | Birchfield Creek | AS-2 | Wise | VA | 13-Mar-99 | RRK | N/A | . | . | . | . |
| 51 | Hominy Creek tributary | AS-1 | Whitley | KY | 21-May-98 | RRK | Technical Water Laboratories, Inc. | . | . | . | 14.00 |
| 52 | Hominy Creek | AS-2 | Whitley | KY | 21-May-98 | RRK | Technical Water Laboratories, Inc. | . | . | . | 8.00 |
| 53 | Hominy Creek | AS-3 | Whitley | KY | 21-May-98 | RRK | Technical Water Laboratories, Inc. | . | . | . | 6.00 |
| 54 | Jellico Creek | AS-4 | Whitley | KY | 21-May-98 | RRK | Technical Water Laboratories, Inc. | . | . | . | 10.00 |
| 55 | Beech Fork | AS-1 | Perry | KY | 11-Jan-99 | RRK | Technical Water Laboratories, Inc. | . | . | . | . |
| 56 | Beech Fork | AS-2 | Perry | KY | 11-Jan-99 | RRK | Technical Water Laboratories, Inc. | . | . | . | . |
| 57 | Beech Fork | AS-3 | Perry | KY | 11-Jan-99 | RRK | Technical Water Laboratories, Inc. | . | . | . | . |
| 58 | Big Branch | AS-1 | Breathitt | KY | 29-Aug-98 | RRK | Technical Water Laboratories, Inc. | . | . | . | . |
| 59 | North Fork Kentucky River tributary | AS-2 | Breathitt | KY | 29-Aug-98 | RRK | Technical Water Laboratories, Inc. | . | . | . | . |
| 60 | John Littles Branch | AS-3 | Breathitt | KY | 29-Aug-98 | RRK | Technical Water Laboratories, Inc. | . | . | . | . |
| 61 | Line Fork Creek | AS-1 | Letcher | KY | 19-Jun-98 | RRK | Technical Water Laboratories, Inc. | . | . | . | . |
| 62 | Line Fork Creek | AS-2 | Letcher | KY | 19-Jun-98 | RRK | Technical Water Laboratories, Inc. | . | . | . | . |
| 63 | Long Branch | AS-3 | Letcher | KY | 19-Jun-98 | RRK | Technical Water Laboratories, Inc. | . | . | . | . |
| 64 | Long Branch | AS-4 | Letcher | KY | 19-Jun-98 | RRK | Technical Water Laboratories, Inc. | . | . | . | . |
| 65 | Long Branch | AS-5 | Letcher | KY | 19-Jun-98 | RRK | Technical Water Laboratories, Inc. | . | . | . | . |
| 66 | Long Branch tributary | AS-6 | Letcher | KY | 19-Jun-98 | RRK | Technical Water Laboratories, Inc. | . | . | . | . |
| 67 | Right Fork Beaver Creek | AS-1 | Knott | KY | 16-Sep-98 | RRK | Technical Water Laboratories, Inc. | . | . | . | . |
| 68 | Right Fork Beaver Creek | AS-2 | Knott | KY | 16-Sep-98 | RRK | Technical Water Laboratories, Inc. | . | . | . | . |
| 69 | Richie Branch | AS-1 | Breathitt | KY | 13-Aug-98 | RRK | Technical Water Laboratories, Inc. | . | . | . | . |
| 70 | Richie Branch | AS-2 | Breathitt | KY | 13-Aug-98 | RRK | Technical Water Laboratories, Inc. | . | . | . | . |
| 71 | EFLSR | AS-1 | Greenup | KY | 18-Sep-97 | RRK | Eco-Tech, Inc. hand held meters | . | . | . | 16.00 |
| 72 | Pond Creek | AS-1 | Pike | KY | 26-May-96 | RRK | Eco-Tech, Inc. hand held meters | . | . | . | . |
| 73 | Trace Fork | AS-1 | Letcher | KY | 6-Jun-00 | TEH | Environmental Monitoring, Inc. | . | . | . | 4.63 |
| 74 | Trace Fork | AS-2 | Letcher | KY | 6-Jun-00 | TEH | Environmental Monitoring, Inc. | . | . | . | 3.80 |
| 75 | Trace Fork | AS-3 | Letcher | KY | 6-Jun-00 | TEH | Environmental Monitoring, Inc. | . | . | . | 6.76 |
| 76 | Trace Fork | AS-4 | Letcher | KY | 6-Jun-00 | TEH | Environmental Monitoring, Inc. | . | . | . | 2.70 |
| 77 | Potcamp Fork | AS-1 | Wise | VA | 23-Mar-00 | RRK | ATS hand held meters | . | . | . | 13.90 |
| 78 | Potcamp Fork | AS-2 | Wise | VA | 23-Mar-00 | RRK | ATS hand held meters | . | . | . | 6.63 |
| 79 | Whitley Fork | AS-3 | Wise | VA | 23-Mar-00 | RRK | ATS hand held meters | . | . | . | 0.71 |
| 80 | Whitley Fork | AS-4 | Wise | VA | 23-Mar-00 | RRK | ATS hand held meters | . | . | . | 5.04 |
| 81 | Whitley Fork | AS-5 | Wise | VA | 23-Mar-00 | RRK | ATS hand held meters | . | . | . | 6.52 |
| 82 | Potcamp Fork tributary | AS-6 | Wise | VA | 23-Mar-00 | RRK | ATS hand held meters | . | . | . | 0.59 |
| 83 | Nine Mile Spur | AS-1 | Wise | VA | 22-Mar-00 | RRK | ATS hand held meters | . | . | . | 15.30 |
| 84 | Nine Mile Spur | AS-2 | Wise | VA | 24-Mar-00 | RRK | ATS hand held meters | . | . | . | 0.50 |
| 85 | Nine Mile Spur | AS-3 | Wise | VA | 24-Mar-00 | RRK | ATS hand held meters | . | . | . | 10.96 |
| 86 | Nine Mile Spur | AS-4 | Wise | VA | 24-Mar-00 | RRK | ATS hand held meters | . | . | . | 7.55 |

**Table 1. Coalfield water quality and biometric data used in developing multi-parameter regression model. (Part 3 of 12)**

| Record | Location | Site ID | County | State | Date | Collectors | H2O Lab | Total Zinc | Settable Solids | Hardness | Turbidity |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 87 | Nine Mile Spur | AS-5 | Wise | VA | 24-Mar-00 | RRK | ATS hand held meters | . | . | . | 8.27 |
| 88 | Nine Mile Spur | AS-6 | Wise | VA | 24-Mar-00 | RRK | ATS hand held meters | . | . | . | 16.30 |
| 89 | Nine Mile Spur | AS-8 | Wise | VA | 22-Mar-00 | RRK | ATS hand held meters | . | . | . | 11.70 |
| 90 | Fawn Branch | AS-1 | Lee | VA | 11-Feb-00 | RRK | Environmental Monitoring, Inc. | . | . | . | 10.81 |
| 91 | Fawn Branch | AS-2 | Lee | VA | 11-Feb-00 | RRK | Environmental Monitoring, Inc. | . | . | . | 10.48 |
| 92 | Roda | AS-1 | Wise | VA | 7-Mar-00 | RRK | ATS hand held meters | . | . | . | . |
| 93 | Roda | AS-2 | Wise | VA | 7-Mar-00 | RRK | ATS hand held meters | . | . | . | . |
| 94 | Roda | AS-3 | Wise | VA | 7-Mar-00 | RRK | ATS hand held meters | . | . | . | . |
| 95 | Roda | AS-4 | Wise | VA | 7-Mar-00 | RRK | ATS hand held meters | . | . | . | . |
| 96 | Mud Lick Creek | AS-1 | Wise | VA | 10-Apr-01 | RRK,THE | Environmental Monitoring, Inc. | . | . | . | 7.50 |
| 97 | Mud Lick Creek tributary | AS-2 | Wise | VA | 10-Apr-01 | RRK,THE | Environmental Monitoring, Inc. | . | . | . | 9.38 |
| 98 | Mud Lick Creek tributary | AS-3 | Wise | VA | 9-Apr-01 | RRK,THE | Environmental Monitoring, Inc. | . | . | . | 8.13 |
| 99 | Mud Lick Creek tributary | AS-4 | Wise | VA | 9-Apr-01 | RRK,THE | Environmental Monitoring, Inc. | . | . | . | 4.49 |
| 100 | Mud Lick Creek tributary | AS-5 | Wise | VA | 9-Apr-01 | RRK,THE | Environmental Monitoring, Inc. | . | . | . | 3.60 |
| 101 | Mud Lick Creek tributary | AS-6 | Wise | VA | 9-Apr-01 | RRK,THE | Environmental Monitoring, Inc. | . | . | . | 5.96 |
| 102 | Mud Lick Creek | AS-7 | Wise | VA | 10-Apr-01 | RRK,THE | Environmental Monitoring, Inc. | . | . | . | 18.70 |
| 103 | Line Fork Creek | AS-1 | Letcher | KY | 26-Apr-01 | RRK,THE | Technical Water laboratories, Inc | . | . | . | 2.20 |
| 104 | Little Laurelpatch Branch | AS-2 | Letcher | KY | 26-Apr-01 | RRK,THE | Technical Water laboratories, Inc | . | . | . | 5.50 |
| 105 | Laurelpatch Branch | AS-3 | Letcher | KY | 26-Apr-01 | RRK,THE | Technical Water laboratories, Inc | . | . | . | 4.20 |
| 106 | Laurelpatch Branch | AS-4 | Letcher | KY | 26-Apr-01 | RRK,THE | Technical Water laboratories, Inc | . | . | . | 4.70 |
| 107 | Trace Branch tributary | AS-5 | Letcher | KY | 26-Apr-01 | RRK,THE | Technical Water laboratories, Inc | . | . | . | 17.00 |
| 108 | Trace Branch tributary | AS-6 | Letcher | KY | 26-Apr-01 | RRK,THE | Technical Water laboratories, Inc | . | . | . | 9.10 |
| 109 | Trace Branch | AS-7 | Letcher | KY | 26-Apr-01 | RRK,THE | Technical Water laboratories, Inc | . | . | . | 1.60 |
| 110 | Black Creek - Averages | UBC-1 | Wise | VA | | | | . | . | . | . |
| 111 | Black Creek - Averages | UBC-2 | Wise | VA | | | | . | . | . | . |
| 112 | Black Creek - Averages | UBC-3 | Wise | VA | | | | . | . | . | . |
| 113 | Black Creek - Averages | LBC-1 | Wise | VA | | | | . | . | . | . |
| 114 | Dismal Creek, Above Whitehead | DIS017.94 | Buchanan | VA | 8-Jun-00 | DEQ-Cumbow | | . | . | . | . |
| 115 | Dismal Creek, Above Whitehead | DIS017.94 | Buchanan | VA | 15-Sep-99 | DEQ-Cumbow | | . | . | . | . |
| 116 | Dumps Creek - Averages | DUM001.09 | | | | | | . | . | . | . |
| 117 | N. F. Holston | NFH098.47 | Smyth | VA | 11-Apr-95 | DEQ-Cumbow | | . | . | . | . |
| 118 | N. F. Holston | NFH098.47 | Smyth | VA | 27-Nov-95 | DEQ-Cumbow | | . | . | . | . |
| 119 | N. F. Holston | NFH098.47 | Smyth | VA | 22-May-97 | DEQ-Cumbow | | . | . | . | . |
| 120 | N. F. Holston | NFH098.47 | Smyth | VA | 7-Oct-97 | DEQ-Cumbow | | . | . | . | . |
| 121 | N. F. Holston | NFH098.47 | Smyth | VA | 29-Jun-98 | DEQ-Cumbow | | . | . | . | . |
| 122 | N. F. Holston | NFH098.47 | Smyth | VA | 2-Dec-98 | DEQ-Cumbow | | . | . | . | . |
| 123 | S. F. Powell | PLL002.55 | Wise | VA | 18-Apr-96 | DEQ-Cumbow | | . | . | . | . |
| 124 | S. F. Powell | PLL002.55 | Wise | VA | 20-Nov-97 | DEQ-Cumbow | | . | . | . | . |
| 125 | S. F. Powell | PLL002.55 | Wise | VA | 31-Aug-98 | DEQ-Cumbow | | . | . | . | . |
| 126 | S. F. Powell | PLL006.50 | Wise | VA | 31-Aug-98 | DEQ-Cumbow | | . | . | . | . |
| 127 | S. F. Powell | PLL006.50 | Wise | VA | 8-Sep-99 | DEQ-Cumbow | | . | . | . | . |
| 128 | Sinking Creek | SNK001.03 | Scott | VA | 14-Dec-95 | DEQ-Cumbow | | . | . | . | . |
| 129 | Black Creek | UBC-1 | Wise | VA | 11-Oct-01 | | | . | . | . | . |
| 130 | Black Creek | LBC-5 | Wise | VA | 11-Oct-01 | | | . | . | . | . |

**Table 1. Coalfield water quality and biometric data used in developing multi-parameter regression model. (Part 4 of 12)**

| Record | Location | Site ID | County | State | Date | Collectors | H2O Lab | Total Zinc | Settable Solids | Hardness | Turbidity |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 131 | Black Creek | UBC-2 | Wise | VA | 11-Oct-01 | | | . | . | . | . |
| 132 | Levisa Fork, Above con. W/SlateCr | LEV143.80 | Buchanan | VA | 26-Nov-01 | DMR-Yates | Summit Engineering Inc. | . | . | . | . |
| 133 | Dismal Creek, Above Whitewood | DIS017.94 | Buchanan | VA | 11/26/01 | DMR-Yates | Summit Engineering Inc. | . | . | . | . |
| 134 | Levisa Fork, At VA-KY state line | LEV130.29 | Buchanan | VA | 11/26/01 | DMR-Abshire | Summit Engineering Inc. | . | . | . | . |
| 135 | Garden Creek, Off Rt. 624 | GAR000.16 | Buchanan | VA | 11/26/01 | DMR-Yates | Summit Engineering Inc. | . | . | . | . |
| 136 | Russell Prater, Haysi, Rt. 767 | RPC000.52 | Dickenson | VA | 11/26/01 | DMR - Yates | Summit Engineering Inc. | . | . | . | . |
| 137 | McClure River, In Haysi | MCR000.55 | Dickenson | VA | 11/26/01 | DMR - Yates | Summit Engineering Inc. | . | . | . | . |
| 138 | Lick Creek, Rt. 63 @ pump station | LCC006.44 | Russell | VA | 11/26/01 | DMR - Yates | Summit Engineering Inc. | . | . | . | . |
| 139 | Fryingpan Creek, Off Rt. 80 | FRY002.25 | Buchanan | VA | 11/26/01 | DMR - Yates | Summit Engineering Inc. | . | . | . | . |
| 140 | Dumps Creek, Rt. 615 bridge | DUM001.09 | Russell | VA | 11/26/01 | DMR - Yates | Summit Engineering Inc. | . | . | . | . |
| 141 | Clinch River, Above APCO | CLN269.57 | Russell | VA | 11/26/01 | DMR - Yates | Summit Engineering Inc. | . | . | . | . |
| 142 | Big Cedar Creek, Rt. 721 | BCD001.84 | Russell | VA | 11/26/01 | DMR - Yates | Summit Engineering Inc. | . | . | . | . |
| 143 | Lewis Creek, Rt. 624, below STP | LWS000.90 | Russell | VA | 11/26/01 | DMR - Yates | Summit Engineering Inc. | . | . | . | . |
| 144 | Bailey's Trace, Rt. 634 | BAI000.26 | Lee | VA | 10/31/01 | DMR - O'Quinn | Environmental Monitoring, Inc. | . | . | . | . |
| 145 | Straight Creek, Below con. W/StoneCr | SRA000.11 | Lee | VA | 10/31/01 | DMR - O'Quinn | Environmental Monitoring, Inc. | . | . | . | . |
| 146 | Big Moccasin Creek, Rte 796 bridge | BMC004.36 | Scott | VA | 12/18/01 | DMR-Abshire | Summit Engineering Inc. | . | . | . | . |
| 147 | Clinch River, at Tennessee St. Line | CLN203.54 | Scott | VA | 12/18/01 | DMR-Abshire | Summit Engineering Inc. | . | . | . | . |
| 148 | South Fork Powell River, off Rte 613 | PLL002.55 | Wise | VA | 12/18/01 | DMR-Abshire | Summit Engineering Inc. | . | . | . | . |
| 149 | South Fork Powell River, Rte 616 | PLL006.50 | Wise | VA | 12/18/01 | DMR-Abshire | Summit Engineering Inc. | . | . | . | . |
| 150 | Pound River, Rte 666 bridge | PNR028.76 | Wise | VA | 12/18/01 | DMR-Abshire | Summit Engineering Inc. | . | . | . | . |
| 151 | South Fork Pound River,1/2 mile above N.F. Pound | PNS000.40 | Wise | VA | 12/18/01 | DMR-Abshire | Summit Engineering Inc. | . | . | . | . |
| 152 | South Fork Pound River,Rte 671@Roberts Pound | PNS004.98 | Wise | VA | 12/18/01 | DMR-Abshire | Summit Engineering Inc. | . | . | . | . |
| 153 | South Fork Pound River,Rte 627below mining operation | PNS008.73 | Wise | VA | 12/18/01 | DMR-Abshire | Summit Engineering Inc. | . | . | . | . |
| 154 | Sinking Creek, Rte 683 | SNK001.03 | Scott | VA | 12/18/01 | DMR-Abshire | Summit Engineering Inc. | . | . | . | . |
| 155 | Stock Creek, below Foote Mineral | STO004.73 | Scott | VA | 12/18/01 | DMR-Abshire | Summit Engineering Inc. | . | . | . | . |

**Table 1. Coalfield water quality and biometric data used in developing multi-parameter regression model. (Part 5 of 12)**

| Record | Discharge | Dissolved Manganese | Dissolved Iron | pH | Acidity to pH 8.3 | Alkalinity to pH 4.5 | Total Iron | Total Manganese | Total Suspended Solids | Total Dissolved Solids | Sulfates | H2O Temperature | Specific Conductivity | Dissolved Oxygen |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| 2 | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| 3 | . | . | . | 8.75 | . | . | . | . | . | . | . | . | . | . |
| 4 | . | . | . | 4.89 | . | . | . | . | . | . | . | . | . | . |
| 5 | . | . | . | 7.32 | . | . | . | . | . | . | . | . | . | . |
| 6 | . | . | . | 7.41 | . | . | . | . | . | . | . | . | . | . |
| 7 | . | . | . | 7.40 | . | . | . | . | . | . | . | . | . | . |
| 8 | . | . | . | 6.86 | . | . | . | . | . | . | . | . | . | . |
| 9 | . | . | . | 7.70 | . | . | . | . | . | . | . | . | . | . |
| 10 | . | . | . | 8.17 | . | . | . | . | . | . | . | . | . | . |
| 11 | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| 12 | 2.400 | 0.01 | 0.01 | 8.88 | 0.50 | 134.00 | 1.020 | 0.130 | 75.00 | 731.00 | 393.00 | 18.10 | 865.00 | 3.66 |
| 13 | 0.500 | 0.01 | 0.01 | 8.89 | 0.50 | 147.00 | 0.690 | 0.080 | 50.00 | 862.00 | 413.00 | 17.30 | 934.00 | 3.22 |
| 14 | 1.700 | 0.03 | 0.21 | 9.14 | 0.50 | 123.00 | 4.000 | 0.380 | 177.00 | 706.00 | 393.00 | 16.90 | 784.00 | 2.84 |
| 15 | 0.500 | 0.01 | 0.06 | 8.70 | 0.50 | 104.00 | 7.000 | 0.620 | 268.00 | 504.00 | 309.00 | 20.70 | 608.00 | 2.96 |
| 16 | 26.200 | 0.09 | 0.06 | 7.79 | 0.50 | 80.70 | 0.150 | 0.200 | 9.00 | 60.00 | 26.00 | 8.60 | 102.00 | 5.64 |
| 17 | 35.100 | 0.14 | 0.17 | 7.40 | 0.50 | 80.96 | 0.220 | 0.260 | 11.00 | 65.00 | 30.00 | 8.40 | 110.00 | 7.60 |
| 18 | 4.900 | 0.25 | 0.19 | 7.94 | 0.50 | 81.10 | 0.310 | 0.400 | 9.00 | 73.00 | 33.00 | 9.20 | 124.00 | 5.67 |
| 19 | 7.600 | 0.13 | 0.12 | 7.60 | 0.50 | 83.44 | 0.250 | 0.320 | 10.00 | 72.00 | 27.00 | 8.30 | 122.00 | 3.68 |
| 20 | 3.300 | 0.04 | 0.08 | 7.86 | 0.50 | 81.36 | 0.100 | 0.220 | 11.00 | 65.00 | 30.00 | 8.00 | 110.00 | 3.86 |
| 21 | 7.200 | 0.02 | 0.01 | 7.50 | 0.50 | 110.04 | 0.030 | 0.050 | 1.00 | 319.00 | 60.00 | 6.70 | 540.00 | 15.00 |
| 22 | 7.700 | 0.16 | 0.16 | 7.70 | 0.50 | 111.02 | 0.200 | 0.200 | 2.00 | 419.00 | 60.00 | 6.70 | 710.00 | 15.00 |
| 23 | 8.600 | 0.15 | 0.21 | 7.80 | 0.50 | 111.06 | 0.250 | 0.200 | 1.00 | 419.00 | 55.00 | 6.10 | 710.00 | 15.00 |
| 24 | . | 0.06 | 0.01 | 7.90 | 0.50 | 115.00 | 0.010 | 0.100 | 2.00 | 83.00 | 35.00 | 5.60 | 140.00 | 7.00 |
| 25 | 0.300 | 0.01 | 0.24 | 7.30 | 0.50 | 79.00 | 0.300 | 0.020 | 2.00 | 71.00 | 25.00 | 10.00 | 120.00 | 6.00 |
| 26 | . | 0.06 | 0.43 | 7.40 | 0.50 | 84.00 | 0.500 | 0.100 | 7.00 | 24.00 | 10.00 | 16.70 | 40.00 | 13.00 |
| 27 | 1.990 | 0.03 | 0.24 | 8.20 | 0.50 | 110.00 | 0.300 | 0.060 | 14.00 | 212.00 | 95.00 | 15.60 | 360.00 | 16.00 |
| 28 | . | 0.01 | 0.10 | 7.90 | 0.50 | 125.00 | 0.140 | 0.010 | 6.00 | 47.00 | 25.00 | 15.60 | 80.00 | 10.00 |
| 29 | 2.690 | 0.01 | 0.10 | 7.90 | 0.50 | 93.00 | 0.120 | 0.040 | 5.00 | 224.00 | 85.00 | 15.00 | 380.00 | 18.00 |
| 30 | . | 0.42 | 0.21 | 7.80 | 0.50 | 121.00 | 0.290 | 0.500 | 11.00 | 106.00 | 65.00 | 17.80 | 180.00 | 12.00 |
| 31 | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| 32 | 0.110 | 0.38 | 0.10 | 7.80 | 0.50 | 102.00 | 0.130 | 0.430 | 8.00 | 59.00 | 35.00 | 17.20 | 100.00 | 10.00 |
| 33 | 0.660 | 0.01 | 0.09 | 7.50 | 0.50 | 89.00 | 0.120 | 0.020 | 10.00 | 106.00 | 55.00 | 17.20 | 180.00 | 12.00 |
| 34 | . | 0.13 | 0.04 | 7.30 | 0.50 | 128.00 | 0.080 | 0.190 | 11.00 | 130.00 | 80.00 | 17.80 | 220.00 | 9.00 |
| 35 | . | 0.02 | 0.23 | 7.70 | 0.50 | 135.00 | 0.300 | 0.060 | 15.00 | 177.00 | 90.00 | 16.70 | 300.00 | 7.00 |
| 36 | . | 0.12 | 4.35 | 8.00 | 0.50 | 141.00 | 4.500 | 0.170 | 25.00 | 148.00 | 70.00 | 17.20 | 250.00 | 11.00 |
| 37 | 0.360 | 0.16 | 0.43 | 7.30 | 0.50 | 109.00 | 0.500 | 0.200 | 9.00 | 71.00 | 40.00 | 17.80 | 120.00 | 8.00 |
| 38 | 10.500 | . | . | 7.50 | . | . | 0.200 | 0.050 | . | . | . | 6.00 | 155.00 | . |
| 39 | 0.350 | . | . | 7.50 | . | . | 0.000 | 0.000 | . | . | . | 8.00 | 110.00 | . |
| 40 | 28.800 | . | . | 7.50 | . | . | 0.120 | 0.100 | . | . | . | 9.50 | 150.00 | . |
| 41 | 0.400 | . | . | 7.30 | . | . | 0.060 | 0.100 | . | . | . | 9.00 | 95.00 | . |
| 42 | 96.000 | . | . | 7.40 | . | . | 0.050 | 0.100 | . | . | . | 10.00 | 330.00 | . |
| 43 | 216.000 | . | . | 7.50 | . | . | 0.170 | 0.050 | . | . | . | 10.00 | 280.00 | . |

**Table 1. Coalfield water quality and biometric data used in developing multi-parameter regression model. (Part 6 of 12)**

| Record | Discharge | Dissolved Manganese | Dissolved Iron | pH | Acidity to pH 8.3 | Alkalinity to pH 4.5 | Total Iron | Total Manganese | Total Suspended Solids | Total Dissolved Solids | Sulfates | H2O Temperature | Specific Conductivity | Dissolved Oxygen |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 44 | . | . | . | 7.50 | . | . | 0.000 | 0.100 | . | . | . | 11.00 | 81.00 | . |
| 45 | 0.400 | 0.01 | 0.01 | 8.20 | 0.50 | 110.00 | 0.040 | 0.010 | 2.00 | 47.00 | 20.00 | 12.20 | 80.00 | 17.00 |
| 46 | 0.400 | 0.01 | 0.01 | 8.20 | 0.50 | 108.00 | 0.030 | 0.010 | 3.00 | 47.00 | 18.00 | 12.20 | 82.00 | 16.00 |
| 47 | 0.600 | 0.01 | 0.02 | 8.20 | 0.50 | 115.00 | 0.080 | 0.030 | 2.00 | 60.00 | 30.00 | 12.20 | 110.00 | 16.00 |
| 48 | . | 0.01 | 0.01 | 7.70 | 0.50 | 110.70 | 0.060 | 0.020 | 1.00 | 21.00 | 5.00 | 5.50 | 52.30 | 4.93 |
| 49 | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| 50 | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| 51 | 1.000 | 0.63 | 0.10 | 8.00 | 17.00 | 40.00 | 0.150 | 0.630 | 5.00 | 106.00 | 75.00 | 12.20 | 180.00 | . |
| 52 | 3.000 | 0.03 | 0.02 | 8.00 | 20.00 | 60.00 | 0.050 | 0.050 | 6.00 | 130.00 | 90.00 | 12.80 | 220.00 | . |
| 53 | 5.000 | 0.05 | 0.03 | 7.20 | 18.00 | 60.00 | 0.050 | 0.070 | 5.00 | 124.00 | 80.00 | 12.20 | 210.00 | . |
| 54 | 110.000 | 0.00 | 0.07 | 7.40 | 23.00 | 44.00 | 0.100 | 0.010 | 15.00 | 83.00 | 30.00 | 12.80 | 140.00 | . |
| 55 | 6.800 | 0.10 | 0.58 | 7.21 | 0.50 | 12.00 | 0.620 | 0.130 | 7.00 | 53.00 | 10.00 | 3.90 | 90.00 | 12.00 |
| 56 | 4.500 | 0.10 | 0.53 | 7.19 | 0.50 | 12.00 | 0.580 | 0.120 | 5.00 | 47.00 | 9.00 | 3.90 | 80.00 | 13.00 |
| 57 | 4.800 | 0.07 | 0.54 | 7.17 | 0.50 | 12.00 | 0.600 | 0.100 | 5.00 | 47.00 | 9.00 | 3.90 | 80.00 | 13.00 |
| 58 | 0.240 | 0.01 | 0.02 | 7.70 | 0.50 | 30.00 | 0.050 | 0.020 | 12.00 | 18.00 | 5.00 | 17.80 | 30.00 | 12.00 |
| 59 | . | 0.01 | 0.01 | 7.80 | 0.50 | 28.00 | 0.040 | 0.010 | 10.00 | 18.00 | 8.00 | 17.80 | 30.00 | 8.00 |
| 60 | 0.320 | 0.01 | 0.02 | 8.00 | 0.50 | 35.00 | 0.050 | 0.020 | 8.00 | 18.00 | 5.00 | 17.80 | 30.00 | 12.00 |
| 61 | 7.700 | 0.01 | 0.05 | 8.20 | 20.00 | 100.00 | 0.080 | 0.020 | 5.00 | 59.00 | 20.00 | 13.90 | 100.00 | 10.00 |
| 62 | 9.200 | 0.01 | 0.02 | 8.30 | 30.00 | 80.00 | 0.050 | 0.010 | 8.00 | 59.00 | 10.00 | 13.90 | 100.00 | 11.00 |
| 63 | 0.700 | 0.01 | 0.01 | 8.30 | 20.00 | 42.00 | 0.090 | 0.010 | 10.00 | 24.00 | 8.00 | 15.00 | 40.00 | 9.00 |
| 64 | 0.500 | 0.01 | 0.02 | 8.50 | 16.00 | 44.00 | 0.050 | 0.010 | 5.00 | 18.00 | 10.00 | 14.40 | 30.00 | 9.00 |
| 65 | . | 0.01 | 0.11 | 8.40 | 12.00 | 60.00 | 0.150 | 0.020 | 8.00 | 18.00 | 10.00 | 14.40 | 30.00 | 8.00 |
| 66 | 0.400 | 0.01 | 0.07 | 8.20 | 15.00 | 58.00 | 0.100 | 0.020 | 5.00 | 24.00 | 10.00 | 13.90 | 40.00 | 7.00 |
| 67 | 5.600 | 0.10 | 0.26 | 7.70 | 0.50 | 125.00 | 0.300 | 0.150 | 15.00 | 370.00 | 160.00 | 16.10 | 30.00 | 7.00 |
| 68 | 6.100 | 0.14 | 0.30 | 7.70 | 0.50 | 134.00 | 0.350 | 0.200 | 18.00 | 372.00 | 140.00 | 16.10 | 630.00 | 7.00 |
| 69 | . | 0.01 | 0.13 | 8.00 | 0.50 | 80.00 | 0.180 | 0.030 | 8.00 | 113.00 | 60.00 | 10.00 | 191.00 | 12.00 |
| 70 | . | 0.01 | 0.02 | 8.10 | 0.50 | 98.00 | 0.060 | 0.010 | 11.00 | 71.00 | 40.00 | 10.50 | 120.00 | 11.00 |
| 71 | . | . | . | 5.90 | 124.00 | . | 0.700 | . | . | . | 90.00 | 22.00 | 550.00 | . |
| 72 | . | . | . | 7.60 | . | . | 2.000 | . | . | . | 40.00 | 17.00 | 425.00 | . |
| 73 | 1.785 | . | . | 9.14 | 0.50 | 57.00 | 0.850 | 0.110 | 17.00 | 198.00 | 30.00 | 15.50 | 290.00 | 2.03 |
| 74 | 1.172 | . | . | 9.04 | 0.50 | 41.00 | 10.200 | 1.330 | 15.00 | 154.00 | 32.00 | 19.30 | 260.00 | 1.93 |
| 75 | 0.355 | . | . | 9.09 | 0.50 | 22.00 | 1.600 | 0.410 | 14.00 | 67.00 | 17.00 | 14.60 | 100.00 | 1.76 |
| 76 | 0.701 | . | . | 8.56 | 0.50 | 50.00 | 0.980 | 0.170 | 15.00 | 198.00 | 61.00 | 15.20 | 300.00 | 1.82 |
| 77 | 29.850 | . | . | 8.54 | . | . | . | . | . | . | . | 14.60 | 585.00 | 1.78 |
| 78 | 17.270 | . | . | 8.60 | . | . | . | . | . | . | . | 15.00 | 760.00 | 1.96 |
| 79 | 2.360 | . | . | 8.38 | . | . | . | . | . | . | . | 10.20 | 130.70 | 1.55 |
| 80 | 2.510 | . | . | 8.57 | . | . | . | . | . | . | . | 10.40 | 128.10 | 1.70 |
| 81 | 3.230 | . | . | 8.29 | . | . | . | . | . | . | . | 10.50 | 90.70 | 2.34 |
| 82 | 1.690 | . | . | 8.80 | . | . | . | . | . | . | . | 9.00 | 83.20 | 2.23 |
| 83 | . | . | . | 8.61 | . | . | . | . | . | . | . | 12.60 | 177.30 | 2.56 |
| 84 | . | . | . | 8.85 | . | . | . | . | . | . | . | 11.20 | 44.90 | 1.60 |
| 85 | . | . | . | 8.50 | . | . | . | . | . | . | . | 11.90 | 171.60 | 2.06 |
| 86 | . | . | . | 8.58 | . | . | . | . | . | . | . | 14.10 | 188.50 | 1.51 |

**Table 1. Coalfield water quality and biometric data used in developing multi-parameter regression model. (Part 7 of 12)**

| Record | Discharge | Dissolved Manganese | Dissolved Iron | pH | Acidity to pH 8.3 | Alkalinity to pH 4.5 | Total Iron | Total Manganese | Total Suspended Solids | Total Dissolved Solids | Sulfates | H2O Temperature | Specific Conductivity | Dissolved Oxygen |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 87 | . | . | . | 8.51 | . | . | . | . | . | . | . | 13.30 | 176.80 | 2.33 |
| 88 | . | . | . | 8.49 | . | . | . | . | . | . | . | 13.00 | 196.50 | 2.19 |
| 89 | . | . | . | 8.45 | . | . | . | . | . | . | . | 11.20 | 104.00 | 3.15 |
| 90 | . | . | . | 8.69 | 0.50 | 59.00 | 0.330 | 0.050 | 22.00 | 180.00 | 82.00 | 7.20 | 191.60 | 2.37 |
| 91 | . | . | . | 8.76 | 0.50 | 58.00 | 1.100 | 0.080 | 18.00 | 168.00 | 127.00 | 7.00 | 197.40 | 2.72 |
| 92 | . | . | . | 9.56 | . | . | . | . | . | . | . | 14.80 | 337.70 | 4.38 |
| 93 | . | . | . | 9.31 | . | . | . | . | . | . | . | 14.10 | 348.70 | 3.86 |
| 94 | . | . | . | 8.13 | . | . | . | . | . | . | . | 9.30 | 132.80 | 5.14 |
| 95 | . | . | . | 8.80 | . | . | . | . | . | . | . | 10.80 | 265.40 | 4.70 |
| 96 | . | . | . | 8.72 | 0.50 | 112.00 | 0.160 | 0.040 | 18.00 | 232.00 | 53.00 | 18.40 | 474.00 | 1.25 |
| 97 | . | . | . | 8.31 | 0.50 | 22.00 | 0.150 | 0.050 | 24.00 | 64.00 | 19.00 | 14.30 | 38.20 | 1.63 |
| 98 | . | . | . | 7.77 | 0.50 | 22.00 | 0.150 | 0.040 | 12.00 | 40.00 | 16.00 | 14.80 | 83.20 | 3.91 |
| 99 | . | . | . | 8.35 | 0.50 | 80.00 | 0.070 | 0.020 | 6.00 | 1545.00 | 13.00 | 14.30 | 237.90 | 3.29 |
| 100 | . | . | . | 8.39 | 0.50 | 106.00 | 0.130 | 0.030 | 8.00 | 238.00 | 20.00 | 13.20 | 247.20 | 3.61 |
| 101 | . | . | . | 8.28 | 0.50 | 76.00 | 0.110 | 0.010 | 9.00 | 154.00 | 17.00 | 12.70 | 189.60 | 4.29 |
| 102 | . | . | . | 8.40 | 0.50 | 87.00 | 0.440 | 0.070 | 30.00 | 558.00 | 130.00 | 14.50 | 678.00 | 2.43 |
| 103 | . | . | . | 8.18 | 0.50 | 80.00 | 0.150 | 0.110 | 2.00 | 50.00 | 25.00 | 11.10 | 151.50 | 2.24 |
| 104 | . | . | . | 8.11 | 0.50 | 33.00 | 0.300 | 0.160 | 1.00 | 77.00 | 66.00 | 12.50 | 52.80 | 2.00 |
| 105 | . | . | . | 8.01 | 0.50 | 40.00 | 0.300 | 0.140 | 3.00 | 65.00 | 70.00 | 13.40 | 99.00 | 1.95 |
| 106 | . | . | . | 8.49 | 0.50 | 75.00 | 0.220 | 0.300 | 5.00 | 80.00 | 36.00 | 14.30 | 108.10 | 1.97 |
| 107 | . | . | . | 8.13 | 0.50 | 15.00 | 0.200 | 0.110 | 2.00 | 24.00 | 46.00 | 11.40 | 61.90 | 2.29 |
| 108 | . | . | . | 8.01 | 0.50 | 26.00 | 0.180 | 0.060 | 3.00 | 38.00 | 29.00 | 11.40 | 66.30 | 2.19 |
| 109 | . | . | . | 7.88 | 0.50 | 82.00 | 0.260 | 0.900 | 4.00 | 40.00 | 45.00 | 12.80 | 192.50 | 2.02 |
| 110 | . | 0.08 | 0.22 | 7.03 | 0.05 | 73.50 | 0.314 | 8.282 | 16.75 | 172.03 | 62.89 | 5.60 | 397.29 | . |
| 111 | . | 0.08 | 0.22 | 7.23 | 0.05 | 36.90 | 0.100 | 0.120 | 9.00 | 300.80 | 170.75 | 11.60 | 492.50 | . |
| 112 | . | 0.08 | 0.22 | 7.24 | 7.45 | 37.48 | 1.760 | 1.530 | 22.76 | 676.81 | 443.74 | 13.23 | 894.45 | . |
| 113 | . | 0.08 | 0.22 | 6.81 | 12.73 | 34.49 | 1.090 | 1.180 | 18.71 | 647.78 | 431.17 | 12.78 | 854.54 | . |
| 114 | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| 115 | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| 116 | 7073.7681 | 0.08 | 0.22 | 7.762318 | 0 | 244.08696 | 0.3787879 | 0.1 | 12.826087 | 414.78261 | 80.8 | 13.153846 | 629.66667 | - |
| 117 | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| 118 | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| 119 | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| 120 | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| 121 | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| 122 | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| 123 | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| 124 | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| 125 | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| 126 | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| 127 | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| 128 | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| 129 | . | 0.01 | 0.06 | 7 | 0.5 | 51 | 8.4 | 0.08 | 2 | 275 | 149 | . | 340 | . |
| 130 | . | 0.69 | 0.02 | 7.5 | 0.5 | 58 | 21.2 | 0.84 | 2 | 1145 | 634 | . | 1320 | . |

**Table 1. Coalfield water quality and biometric data used in developing multi-parameter regression model. (Part 8 of 12)**

| Record | Discharge | Dissolved Manganese | Dissolved Iron | pH | Acidity to pH 8.3 | Alkalinity to pH 4.5 | Total Iron | Total Manganese | Total Suspended Solids | Total Dissolved Solids | Sulfates | H2O Temperature | Specific Conductivity | Dissolved Oxygen |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 131 | . | 1.4 | 0.16 | 7.1 | 0.5 | 53 | 0.26 | 1.41 | 2 | 1000 | 548 | . | 1300 | . |
| 132 | . | 0.01 | 0.15 | 7.21 | 0.5 | 179 | 0.15 | 0.01 | 1.2 | 658 | 176 | . | 1007 | . |
| 133 | . | 0.02 | 0.14 | 7.33 | 0.5 | 170 | 0.18 | 0.02 | 10 | 332 | 104 | . | 488 | . |
| 134 | . | 0.02 | 0.11 | 8.65 | 0.5 | 138 | 0.12 | 0.02 | 10 | 702 | 278 | . | 960 | . |
| 135 | . | 0.02 | 0.08 | 7.39 | 0.5 | 204 | 0.09 | 0.02 | 3.2 | 1794 | 181 | . | 2800 | . |
| 136 | . | 0.01 | 0.15 | 7.48 | 0.5 | 103 | 0.16 | 0.02 | 2 | 846 | 508 | . | 909 | . |
| 137 | . | 0.01 | 0.12 | 7 | 0.5 | 237 | 0.15 | 0.01 | 1.6 | 542 | 203 | . | 864 | . |
| 138 | . | 0.05 | 0.08 | 7 | 0.5 | 69 | 0.1 | 0.05 | 24.8 | 394 | 197 | . | 569 | . |
| 139 | . | 0.02 | 0.08 | 8 | 0.5 | 369 | 0.11 | 0.02 | 3.6 | 648 | 148 | . | 925 | . |
| 140 | . | 0.02 | 0.09 | 8.63 | 0.5 | 444 | 0.13 | 0.03 | 2 | 664 | 84 | . | 981 | . |
| 141 | . | 0.02 | 0.04 | 8.41 | 0.5 | 156 | 0.06 | 0.02 | 1.6 | 268 | 31 | . | 382 | . |
| 142 | . | 0.01 | 0.04 | 8.8 | 0.5 | 174 | 0.06 | 0.01 | 1.2 | 270 | 13.9 | . | 390 | . |
| 143 | . | 0.01 | 0.07 | 8.42 | 0.5 | 134 | 0.09 | 0.02 | 7.2 | 300 | 74 | . | 428 | . |
| 144 | . | 0.01 | 0.03 | 8.5 | 0.5 | 156 | 0.1 | 0.01 | 11 | 1004 | 619 | . | 1070 | . |
| 145 | . | 0.01 | 0.01 | 8.5 | 0.5 | 131 | 0.1 | 0.01 | 7 | 615 | 352 | . | 730 | . |
| 146 | . | 0.01 | 0.07 | 8.1 | 0.5 | 160 | 0.11 | 0.04 | 1.6 | 216 | 3 | . | 310 | . |
| 147 | . | 0.01 | 0.09 | 8.2 | 0.5 | 115 | 0.11 | 0.01 | 2 | 194 | 44 | . | 280 | . |
| 148 | . | 0.03 | 0.19 | 7.7 | 0.5 | 85 | 0.23 | 0.04 | 6 | 182 | 40 | . | 250 | . |
| 149 | . | 0.02 | 0.26 | 7.5 | 0.5 | 26 | 0.31 | 0.02 | 6.8 | 54 | 11 | . | 60 | . |
| 150 | . | 0.14 | 0.15 | 7.9 | 0.5 | 115 | 0.19 | 0.14 | 2.4 | 758 | 431 | . | 850 | . |
| 151 | . | 0.22 | 0.21 | 7.8 | 0.5 | 103 | 0.29 | 0.24 | 1.6 | 782 | 457 | . | 920 | . |
| 152 | . | 0.71 | 0.12 | 8 | 0.5 | 162 | 0.46 | 0.79 | 4.8 | 1218 | 739 | . | 1390 | . |
| 153 | . | 0.9 | 0.16 | 8.1 | 0.5 | 192 | 1.25 | 1.08 | 6 | 1406 | 903 | . | 1580 | . |
| 154 | . | 0.01 | 0.07 | 8 | 0.5 | 194 | 0.09 | 0.01 | 3.2 | 288 | 16 | . | 410 | . |
| 155 | . | 0.02 | 0.12 | 7.8 | 0.5 | 48 | 0.13 | 0.02 | 1.2 | 76 | 12 | . | 110 | . |

**Table 1. Coalfield water quality and biometric data used in developing multi-parameter regression model. (Part 9 of 12)**

| Record | Taxa Richness | Modified Family Biotic Index | Scraper to Filtering Collector Ratio | EPT to Chironomid Ratio | Percent Contribution of Dominant Family | EPT Index | Shredder to Total Ratio |
|---|---|---|---|---|---|---|---|
| 1 | . | . | . | . | . | . | . |
| 2 | . | . | . | . | . | . | . |
| 3 | 7 | 6.491 | 0.000 | 1.000 | 0.273 | 4 | . |
| 4 | 10 | 6.770 | 0.000 | 10.000 | 0.222 | 2 | . |
| 5 | 11 | 6.810 | 0.417 | 0.000 | 0.375 | 0 | . |
| 6 | 5 | 5.757 | 0.000 | 2.000 | 0.286 | 1 | . |
| 7 | 7 | 6.624 | 0.000 | 0.286 | 0.333 | 2 | . |
| 8 | 4 | 8.446 | 0.000 | 0.000 | 0.583 | 0 | . |
| 9 | 8 | 4.920 | 0.000 | 4.333 | 0.481 | 3 | . |
| 10 | 4 | 3.536 | 0.000 | 90.000 | 0.865 | 2 | . |
| 11 | . | . | . | . | . | . | . |
| 12 | . | 4.770 | . | 4.914 | . | . | 0.451 |
| 13 | . | 4.270 | . | 42.250 | . | . | 0.348 |
| 14 | . | 5.810 | . | 8.250 | . | . | 0.235 |
| 15 | . | 4.680 | . | 25.500 | . | . | 0.276 |
| 16 | 18 | 3.837 | 1.111 | 35.300 | 0.214 | 12 | 0.441 |
| 17 | 20 | 3.857 | 0.529 | 6.700 | 0.130 | 10 | 0.123 |
| 18 | 19 | 4.010 | 0.895 | 34.300 | 0.251 | 13 | 0.514 |
| 19 | 20 | 3.789 | 1.083 | 12.100 | 0.120 | 11 | 0.352 |
| 20 | 17 | 3.058 | 0.240 | 17.100 | 0.152 | 11 | 0.284 |
| 21 | 24 | 4.438 | 0.161 | 15.100 | 0.495 | 8 | 0.093 |
| 22 | 22 | 4.633 | 0.099 | 12.800 | 0.624 | 7 | 0.020 |
| 23 | 22 | 4.665 | 0.077 | 14.300 | 0.575 | 8 | 0.008 |
| 24 | 15 | 4.603 | 1.200 | 10.700 | 0.254 | 7 | 0.164 |
| 25 | 20 | 3.637 | 5.467 | 28.100 | 0.431 | 10 | 0.067 |
| 26 | 12 | 4.202 | 6.000 | 19.300 | 0.636 | 6 | 0.039 |
| 27 | 19 | 4.403 | 1.262 | 78.300 | 0.251 | 10 | 0.063 |
| 28 | 10 | 3.956 | 36.000 | 88.000 | 0.386 | 5 | 0.014 |
| 29 | 18 | 4.307 | 4.554 | 143.600 | 0.302 | 10 | 0.171 |
| 30 | 12 | 4.774 | 5.000 | 44.000 | 0.160 | 7 | 0.020 |
| 31 | . | . | . | . | . | . | . |
| 32 | 14 | 3.571 | 3.000 | 27.000 | 0.534 | 8 | 0.041 |
| 33 | 18 | 4.330 | 0.394 | 35.100 | 0.271 | 9 | 0.044 |
| 34 | 16 | 4.290 | 4.636 | 5.800 | 0.238 | 9 | 0.006 |
| 35 | 20 | 4.168 | 0.194 | 22.400 | 0.495 | 11 | 0.047 |
| 36 | 12 | 3.580 | 0.071 | 154.000 | 0.552 | 6 | 0.012 |
| 37 | 21 | 3.774 | 0.369 | 28.800 | 0.283 | 11 | 0.027 |
| 38 | 22 | 4.719 | 13.000 | 4.050 | 0.146 | 12 | 0.128 |
| 39 | 16 | 4.011 | 2.051 | 65.330 | 0.225 | 9 | 0.305 |
| 40 | 21 | 4.508 | 15.500 | 4.240 | 0.205 | 12 | 0.120 |
| 41 | 17 | 4.055 | 8.250 | 37.000 | 0.162 | 9 | 0.370 |
| 42 | 23 | 4.283 | 12.500 | 1.700 | 0.303 | 12 | 0.260 |
| 43 | . | . | . | . | . | . | . |

**Table 1. Coalfield water quality and biometric data used in developing multi-parameter regression model. (Part 10 of 12)**

| Record | Taxa Richness | Modified Family Biotic Index | Scraper to Filtering Collector Ratio | EPT to Chironomid Ratio | Percent Contribution of Dominant Family | EPT Index | Shredder to Total Ratio |
|---|---|---|---|---|---|---|---|
| 44 | . | . | . | . | . | . | . |
| 45 | 17 | 3.414 | 0.613 | 30.750 | 0.259 | 12 | 0.178 |
| 46 | 15 | 3.840 | 0.455 | 94.000 | 0.386 | 13 | 0.075 |
| 47 | 18 | 3.738 | 1.960 | 50.670 | 0.235 | 13 | 0.128 |
| 48 | . | 3.823 | . | 8.120 | . | . | 0.492 |
| 49 | . | 4.911 | . | 2.810 | . | . | 0.073 |
| 50 | . | 5.452 | . | 2.790 | . | . | 0.081 |
| 51 | 12 | 4.965 | 1.000 | 18.000 | 0.243 | 5 | 0.081 |
| 52 | 18 | 4.503 | 0.311 | 25.400 | 0.223 | 9 | 0.094 |
| 53 | 16 | 4.538 | 0.218 | 32.500 | 0.340 | 7 | 0.068 |
| 54 | 16 | 4.180 | 1.944 | 78.000 | 0.274 | 7 | 0.095 |
| 55 | 10 | 6.939 | 0.000 | 4.500 | 0.409 | 4 | 0.455 |
| 56 | 19 | 4.241 | 0.864 | 36.000 | 0.150 | 9 | 0.230 |
| 57 | 16 | 4.630 | 1.895 | 10.000 | 0.242 | 6 | 0.194 |
| 58 | . | . | . | . | . | . | . |
| 59 | 5 | 4.575 | 0.000 | 83.000 | 0.742 | 2 | 0.191 |
| 60 | 17 | 4.557 | 1.120 | 5.290 | 0.251 | 10 | 0.045 |
| 61 | 14 | 4.895 | 1.025 | 3.730 | 0.229 | 5 | 0.011 |
| 62 | 14 | 5.399 | 0.605 | 4.780 | 0.348 | 5 | 0.039 |
| 63 | 19 | 4.123 | 2.000 | 24.250 | 0.364 | 12 | 0.113 |
| 64 | 16 | 3.936 | 1.240 | 8.440 | 0.147 | 10 | 0.266 |
| 65 | 6 | 5.748 | 12.000 | 26.000 | 0.400 | 4 | 0.400 |
| 66 | 15 | 3.668 | 0.156 | 25.000 | 0.348 | 11 | 0.163 |
| 67 | 16 | 5.739 | 0.059 | 44.330 | 0.671 | 6 | 0.035 |
| 68 | 15 | 5.974 | 0.028 | 57.000 | 0.562 | 6 | 0.067 |
| 69 | 15 | 5.126 | 1.000 | 2.500 | 0.188 | 6 | 0.073 |
| 70 | 15 | 4.632 | 0.667 | 2.450 | 0.208 | 6 | 0.049 |
| 71 | . | 5.829 | . | 10.000 | . | . | 0.187 |
| 72 | 12 | 7.155 | 10.000 | 0.000 | 0.160 | 0 | 0.147 |
| 73 | 18 | 4.659 | 0.943 | 1.870 | 0.218 | 8 | 0.000 |
| 74 | 16 | 4.120 | 7.000 | 4.220 | 0.211 | 4 | 0.009 |
| 75 | 18 | 4.197 | 9.500 | 10.500 | 0.238 | 5 | 0.032 |
| 76 | 12 | 4.062 | 3.571 | 0.820 | 0.382 | 6 | 0.029 |
| 77 | . | 4.170 | . | 7.830 | . | . | 0.213 |
| 78 | . | 4.897 | . | 2.680 | . | . | 0.221 |
| 79 | . | 5.051 | . | 2.320 | . | . | 0.178 |
| 80 | . | 3.929 | . | 20.670 | . | . | 0.051 |
| 81 | . | 4.132 | . | 5.000 | . | . | 0.065 |
| 82 | . | 4.790 | . | 21.330 | . | . | 0.539 |
| 83 | . | 4.539 | . | 4.410 | . | . | 0.055 |
| 84 | . | 4.371 | . | 16.130 | . | . | 0.180 |
| 85 | . | 4.072 | . | 21.900 | . | . | 0.086 |
| 86 | . | 3.679 | . | 30.220 | . | . | 0.214 |

**Table 1. Coalfield water quality and biometric data used in developing multi-parameter regression model. (Part 11 of 12)**

| Record | Taxa Richness | Modified Family Biotic Index | Scraper to Filtering Collector Ratio | EPT to Chironomid Ratio | Percent Contribution of Dominant Family | EPT Index | Shredder to Total Ratio |
|---|---|---|---|---|---|---|---|
| 87 | . | 4.099 | . | 116.500 | . | . | 0.107 |
| 88 | . | 3.735 | . | 106.330 | . | . | 0.142 |
| 89 | . | 4.455 | . | 48.330 | . | . | 0.171 |
| 90 | . | 4.064 | . | 15.250 | . | . | 0.089 |
| 91 | . | 4.409 | . | 35.670 | . | . | 0.063 |
| 92 | . | 4.125 | . | 6.090 | . | . | 0.104 |
| 93 | . | 4.843 | . | 0.460 | . | . | 0.010 |
| 94 | . | 4.023 | . | 7.290 | . | . | 0.116 |
| 95 | . | 3.806 | . | 9.890 | . | . | 0.147 |
| 96 | . | 4.666 | . | 8.920 | . | . | 0.067 |
| 97 | . | 4.319 | . | 15.910 | . | . | 0.193 |
| 98 | . | 4.262 | . | 57.500 | . | . | 0.180 |
| 99 | . | 4.395 | . | 7.880 | . | . | 0.078 |
| 100 | . | 4.062 | . | 9.410 | . | . | 0.132 |
| 101 | . | 4.059 | . | 8.760 | . | . | 0.214 |
| 102 | . | 4.295 | . | 1.640 | . | . | 0.144 |
| 103 | . | 4.656 | . | 59.000 | . | . | 0.087 |
| 104 | . | 2.468 | . | 304.000 | . | . | 0.169 |
| 105 | . | 3.166 | . | 306.000 | . | . | 0.012 |
| 106 | . | 2.682 | . | 498.000 | . | . | 0.058 |
| 107 | . | 1.885 | . | 204.000 | . | . | 0.022 |
| 108 | . | . | . | . | . | . | . |
| 109 | . | 2.614 | . | 44.000 | . | . | 0.076 |
| 110 | 11.5 | 2.450 | 10.684 | 25.465 | 0.349 | 4.5 | 0.426 |
| 111 | 4 | 5.700 | 0.000 | 0.000 | 0.748 | 0 | 0.000 |
| 112 | 4 | 5.150 | 0.000 | 3.250 | 0.519 | 1.5 | 0.080 |
| 113 | 8 | 5.000 | 0.000 | 2.795 | 0.465 | 3 | 0.107 |
| 114 | 11 | 4.87 | 0.53 | 2.474 | 0.263 | 5 | 0 |
| 115 | 11 | 4.31 | 0.43 | 17.25 | 0.279 | 5 | 0 |
| 116 | 9.8 | 5.025 | 1.4567 | 3.0282 | 0.3757 | 3.2 | 0.0305 |
| 117 | 17 | 4.69 | 1.08 | 1.647 | 0.257 | 9 | 0.028 |
| 118 | 12 | 3.96 | 34.67 | 14 | 0.695 | 7 | 0.008 |
| 119 | 12 | 4.78 | 9 | 0.882 | 0.306 | 6 | 0 |
| 120 | 18 | 4.09 | 3.56 | 21.5 | 0.333 | 11 | 0.04 |
| 121 | 15 | 3.98 | 7.25 | 3.222 | 0.371 | 8 | 0.021 |
| 122 | 22 | 3.83 | 4.94 | 9.667 | 0.205 | 11 | 0.039 |
| 123 | 8 | 5.24 | 38 | 0.167 | 0.606 | 2 | 0.028 |
| 124 | 14 | 4.23 | 1.5 | 4.667 | 0.296 | 5 | 0.014 |
| 125 | 14 | 3.76 | 24.33 | 10.8 | 0.331 | 6 | 0.154 |
| 126 | 17 | 4.06 | 1.81 | 3.938 | 0.16 | 7 | 0.017 |
| 127 | 13 | 4.08 | 14.4 | 2.9 | 0.33 | 7 | 0 |
| 128 | 18 | 4.51 | 3.39 | 4.2 | 0.299 | 7 | 0.065 |
| 129 | 19 | 2.9 | 0.045 | 1.213 | 0.361 | 8 | 0.13 |
| 130 | 12 | 4.4 | 0.001 | 5.545 | 0.319 | 5 | 0.027 |

**Table 1. Coalfield water quality and biometric data used in developing multi-parameter regression model. (Part 12 of 12)**

| Record | Taxa Richness | Modified Family Biotic Index | Scraper to Filtering Collector Ratio | EPT to Chironomid Ratio | Percent Contribution of Dominant Family | EPT Index | Shredder to Total Ratio |
|---|---|---|---|---|---|---|---|
| 131 | 8 | 2.9 | 0 | 0 | 0.639 | 3 | 0.112 |
| 132 | . | . | . | . | . | . | . |
| 133 | . | . | . | . | . | . | . |
| 134 | . | . | . | . | . | . | . |
| 135 | . | . | . | . | . | . | . |
| 136 | . | . | . | . | . | . | . |
| 137 | . | . | . | . | . | . | . |
| 138 | . | . | . | . | . | . | . |
| 139 | . | . | . | . | . | . | . |
| 140 | 7 | 4.622 | 0.438 | 7.5 | 31.11 | 3 | 0.222 |
| 141 | . | . | . | . | . | . | . |
| 142 | . | . | . | . | . | . | . |
| 143 | 11 | 4.3854167 | 8.571 | 3.857 | 31.25 | 4 | 0.01 |
| 144 | . | . | . | . | . | . | . |
| 145 | . | . | . | . | . | . | . |
| 146 | . | . | . | . | . | . | . |
| 147 | . | . | . | . | . | . | . |
| 148 | 11 | 3.643 | 0.7 | 10.833 | 24.49 | 5 | 0.092 |
| 149 | . | . | . | . | . | . | . |
| 150 | . | . | . | . | . | . | . |
| 151 | . | . | . | . | . | . | . |
| 152 | 6 | 4.938 | 2 | 1 | 47.92 | 1 | 0.021 |
| 153 | . | . | . | . | . | . | . |
| 154 | . | . | . | . | . | . | . |
| 155 | . | . | . | . | . | . | . |

**Attachment B:**

**Parameter estimates for regression models.**

**Taxa Richness Parameter Estimates**

| *Term* | *Estimate* |
|---|---|
| Intercept | -19.47779 |
| Total Dissolved Solids | -0.082476 |
| Sulfates | -0.065347 |
| ln(Dissolved Manganese) | -1.756575 |
| ln(Dissolved Iron) | -3.110254 |
| ln(Total Iron) | 3.358023 |
| ln(Total Manganese) | 2.9930221 |
| ln(Total Dissolved Solids) | 9.1906664 |
| sq(Dissolved Manganese) | -10.75273 |
| sq(pH) | 0.1359932 |
| sq(Alkalinity to pH 8.3)) | -0.000177 |
| sq(Total Iron) | -0.148292 |
| sq(Total Manganese) | -10.09413 |
| sq(Total Dissolved Solids) | 0.0001156 |

**EPT to Chironomid Ratio Parameter Estimates**

| *Term* | *Estimate* |
|---|---|
| Intercept | -3325.491 |
| Dissolved Iron | 30.85465 |
| pH | -394.9192 |
| ln(pH) | 3119.6647 |
| ln(Total Manganese) | -8.784505 |
| ln(Total Dissolved Solids) | -14.163295 |
| ln(Sulfates) | 18.323351 |

**EPT Index Parameter Estimates**

| *Term* | *Estimate* |
|---|---|
| Intercept | -1.23834 |
| Month | -0.410628 |
| Specific Conductivity x Alkalinity | 0.000167 |
| ln(Alkalinity to pH 8.3) | 4.7365244 |
| ln(Total Suspended Solids) | -1.148564 |
| ln(Sulfates) | -1.006621 |
| sq(Dissolved Manganese) | 3.3032895 |
| sq(Acidity to pH 4.5) | -0.004887 |
| sq(Alkalinity to pH 8.3) | -0.000419 |
| sq(Sulfates) | 0.0000862 |
| sq(Specific Conductivity) | -0.000028 |

**MFBI Parameter Estimates**

| *Term* | *Estimate* |
|---|---|
| Intercept | -3.937584 |
| Total Dissolved Solids | 0.007005 |
| TMn x Tfe | 0.1950087 |
| ln(Dissolved Iron) | 0.3784138 |
| ln(pH) | 5.57748689 |
| ln(Alkalinity to pH 8.3) | -0.892412 |
| ln(Total Iron) | -0.414108 |
| sq(Dissolved Iron) | -0.056901 |
| sq(Acidity to pH 4.5) | 0.0006544 |
| sq(Alkalinity to pH 8.3) | 0.0000275 |
| sq(Total Dissolved Solids) | -0.000002 |
| sq(Specific Conductivity) | -0.000003 |

**Shredder to Total Ratio Parameter Estimates**

| *Term* | *Estimate* |
|---|---|
| Intercept | 19.417674 |
| Month | -0.016924 |
| pH | 2.355559 |
| ln(Dissolved Iron) | -0.021438 |
| ln(pH) | -18.19171 |
| ln(Total Manganese) | 0.021432 |
| ln(Sulfates) | -0.043023 |
| sq(Acidity to pH 4.5) | -0.000272 |

**Scraper to Filtering Collector Ratio Parameter Estimates**

| *Term* | *Estimate* |
|---|---|
| Intercept | -2.43554 |
| ln(Dissolved Iron) | 2.1134616 |
| ln(Alkalinity to pH 8.3) | 3.2861161 |
| ln(Total Manganese) | -1.746273 |
| ln(Total Dissolved Solids) | -1.997797 |
| sq(Dissolved Iron) | -0.556723 |
| sq(Total Iron) | 0.0189878 |
| sq(Total Manganese) | 3.8790984 |

**Percent Contribution from Dominant Family Parameter Estimates**

| *Term* | *Estimate* |
|---|---|
| Intercept | -28.54324 |
| Month | 0.0159398 |
| Dissolved Iron | 0.0942137 |
| ln(pH) | 19.456992 |
| ln(Total Dissolved Solids) | 0.325481 |
| ln(Specific Conductivity) | -0.484174 |
| sq(pH) | -0.169424 |
| sq(Acidity to pH 4.5) | 0.0001626 |
| sq(Total Iron) | 0.0014645 |
| sq(Total Manganese) | -0.222145 |
| sq(Total Suspended Solids) | -0.000281 |
| sq(Total Dissolved Solids) | -0.000008 |
| sq(Sulfates) | 0.0000078 |
| sq(Specific Conductivity) | 0.0000037 |

# APPENDIX: B

## BENTHIC REFERENCE STATIONS IN THE COALFIELD REGION OF VIRGINIA

**Table B.1 Benthic reference stations in the coalfield region of Virginia, and sample dates available for inclusion in the variability analysis reported in Section 2.1. (Part 1 of 2)**

| Station ID | Waterbody | County | Dates Sampled |
|---|---|---|---|
| BAI000.26 | Bailey's Trace | Lee | 9/22/99 |
| BCD001.84 | Big Cedar Creek | Russell | 12/6/95 |
| | Big Cedar Creek | Russell | 6/3/97 |
| | Big Cedar Creek | Russell | 6/12/00 |
| BCE111.11 | Big Cedar Creek | Russell | 5/8/95 |
| BMC004.36 | Big Moccasin Creek | Scott | 11/20/97 |
| | Big Moccasin Creek | Scott | 5/18/98 |
| CLN203.54 | Clinch River | Scott | 10/22/96 |
| | Clinch River | Scott | 6/9/99 |
| | Clinch River | Scott | 10/26/99 |
| CLN269.57 | Clinch River | Russell | 5/8/95 |
| | Clinch River | Russell | 10/8/97 |
| | Clinch River | Russell | 9/15/98 |
| | Clinch River | Russell | 11/10/99 |
| | Clinch River | Russell | 6/12/00 |
| DIS017.94 | Dismal Creek | Buchanan | 4/4/96 |
| | Dismal Creek | Buchanan | 4/4/96 |
| | Dismal Creek | Buchanan | 11/12/97 |
| | Dismal Creek | Buchanan | 6/8/00 |
| DIS111.11 | Dismal Creek | Buchanan | 12/8/94 |
| DRK036.38 | Dry Fork | Tazewell | 4/24/96 |
| DRY111.11 | Dry Fork | Tazewell | 11/14/94 |
| FRY002.25 | Fryingpan Creek | Buchanan | 6/19/96 |
| IDI000.55 | Indian Creek | Tazewell | 5/21/96 |
| IDI003.67 | Indian Creek | Tazewell | 10/30/97 |
| KBL007.24 | Kimberling Creek | Bland | 4/28/98 |
| | Kimberling Creek | Bland | 6/21/00 |
| LAC000.92 | Laurel Creek | Bland | 5/19/98 |
| | Laurel Creek | Bland | 11/9/98 |
| | Laurel Creek | Bland | 5/12/99 |
| | Laurel Creek | Bland | 10/28/99 |
| | Laurel Creek | Bland | 6/1/00 |

**Table B.1 Benthic reference stations in the coalfield region of Virginia, and sample dates available for inclusion in the variability analysis reported in Section 2.1. (Part 2 of 2)**

| Station ID | Waterbody | County | Dates Sampled |
|---|---|---|---|
| LEV130.29 | Levisa Fork | Buchanan | 6/23/99 |
| | Levisa Fork | Buchanan | 6/23/99 |
| | Levisa Fork | Buchanan | 6/8/00 |
| | Levisa Fork | Buchanan | 6/8/00 |
| LEV143.80 | Levisa Fork | Buchanan | 11/18/98 |
| MCR000.20 | McClure River | Dickenson | 12/7/94 |
| MCR000.55 | McClure River | Dickenson | 10/13/99 |
| MTN003.56 | Martin Creek | Lee | 4/15/97 |
| NFH007.78 | N. F. Holston | Scott | 10/15/97 |
| PLL001.11 | S.F. Powell | Wise | 8/31/98 |
| PLL002.55 | S.F. Powell | Wise | 11/20/97 |
| PLL006.50 | S.F. Powell | Wise | 8/31/98 |
| | S.F. Powell | Wise | 9/8/99 |
| POW120.12 | Powell River | Lee | 6/15/00 |
| RSS034.53 | Russell Fork | Dickenson | 4/11/96 |
| SFH074.54 | S.F. Holston River | Washington | 9/24/98 |
| SFH111.11 | S.F. Holston River | Washington | 12/1/94 |
| SNK001.03 | Sinking Creek | Scott | 12/14/95 |
| SNY000.23 | Stoney Creek | Scott | 12/14/95 |
| | Stoney Creek | Scott | 5/8/97 |
| | Stoney Creek | Scott | 4/20/99 |
| STN111.11 | Stoney Creek | Scott | 3/28/95 |
| STO005.26 | Stock Creek | Scott | 12/14/95 |
| WAL001.57 | Wallen Creek | Lee | 6/18/98 |
| WFC019.04 | Wolf Creek | Bland | 11/9/98 |
| | Wolf Creek | Bland | 5/12/99 |
| | Wolf Creek | Bland | 10/28/99 |
| WFC034.82 | Wolf Creek | Bland | 5/24/96 |
| | Wolf Creek | Bland | 10/25/96 |
| WLF111.11 | Wolf Creek | Bland | 10/4/94 |
| WLK050.85 | Walker Creek | Bland | 11/8/99 |
| | Walker Creek | Bland | 6/1/00 |

# APPENDIX: C

# PERMITTED POINT SOURCES IN THE BLACK CREEK WATERSHED

Nine point sources were permitted for discharge in the Black Creek watershed (Table C.1) at the onset of this study. Concentration limits are set for each of these discharges based on best available technology and control pH, total suspended solids, iron, and manganese. The pH must be maintained between 6.0 and 9.0. The remaining controlled pollutants must be held below the limits expressed in Table C.2.

**Table C.1 Permitted discharges in the Black Creek watershed, permitted at the onset of this study.**

| Milepoint | CSMO Permit | NPDES Permit | Description | Current Status |
|---|---|---|---|---|
| 0.06 | 1601576 | 0081576 | Interim Pond K | Active |
| 0.42 | 1601576 | 0081576 | Relocated Interim Pond D | Not Discharging |
| 0.59 | 1601576 | 0081576 | Pond 1 established under CSMO Permit 1200755 | Not Discharging |
| 0.68 | 1601576 | 0081576 | Pond 10 established under CSMO Permit 1200755 | Not Discharging |
| 0.69 | 1601576 | 0081576 | Relocated Pond E | Active |
| 1.43 | 1601576 | 0081576 | Ponds 1 and 1A established under CSMO Permit 1201117 Pond L established under CSMO Permit 1601576 | Not Discharging |
| 2.35 | 1201542 | 0081542 | Ponds 1 and 2 | Active |
| 2.43 | 1201542 | 0081542 | Direct Mine Discharge | Not Discharging |
| 2.46+0.07 | 1601576 | 0081576 | Pond G | Not Discharging |

**Table C.2 Maximum concentrations allowed in permitted discharges, based on best available technology.**

| Monthly Average (lbs/day) | | | Daily Maximum (lbs/day) | | |
|---|---|---|---|---|---|
| TSS | Iron | Manganese | TSS | Iron | Manganese |
| 35 | 3.0 | 2.0 | 70 | 6.0 | 4.0 |

## GLOSSARY

**Note: Endnotes indicate the source of definition where appropriate.**

**303(d).** A section of the Clean Water Act of 1972 requiring states to identify and list water bodies that do not meet the states' water quality standards.

**Acid mine drainage**. Acidic run-off water from mine waste dumps and mill tailings ponds containing sulphide minerals. Also refers to ground water pumped to surface from mines.

**Allocations.** That portion of a receiving water's loading capacity attributed to one of its existing or future pollution sources (nonpoint or point) or to natural background sources. (A wasteload allocation [WLA] is that portion of the loading capacity allocated to an existing or future point source, and a load allocation [LA] is that portion allocated to an existing or future nonpoint source or to natural background levels. Load allocations are best estimates of the loading, which can range from reasonably accurate estimates to gross allotments, depending on the availability of data and appropriate techniques for predicting loading.) (1)

**Ambient water quality.** Natural concentration of water quality constituents prior to mixing of either point or nonpoint source load of contaminants. Reference ambient concentration is used to indicate the concentration of a chemical that will not cause adverse impact on human health. (1)

**Anthropogenic.** Pertains to the [environmental] influence of human activities. (1)

**Antidegradation Policies.** Policies that are part of each states water quality standards. These policies are designed to protect water quality and provide a method of assessing activities that might affect the integrity of waterbodies. (1)

**Aquatic ecosystem.** Complex of biotic and abiotic components of natural waters. The aquatic ecosystem is an ecological unit that includes the physical characteristics (such as flow or velocity and depth), the biological community of the water column and benthos, and the chemical characteristics such as dissolved solids, dissolved oxygen, and nutrients. Both living and nonliving components of the aquatic ecosystem interact and influence the properties and status of each component. (1)

**Assimilative capacity.** The amount of contaminant load that can be discharged to a specific waterbody without exceeding water quality standards or criteria. Assimilative capacity is used to define the ability of a waterbody to naturally absorb and use a discharged substance without impairing water quality or harming aquatic life. (1)

**Background levels.** Levels representing the chemical, physical, and biological conditions that would result from natural geomorphological processes such as weathering or dissolution. (1)

**Bacterial decomposition.** Breakdown by oxidation, or decay, of organic matter by heterotrophic bacteria. Bacteria use the organic carbon in organic matter as the energy source for cell synthesis. (1)

**Bench**. One of two or more divisions of a coal seam separated by slate or formed by the process of cutting the coal.

**Benthic.** Refers to material, especially sediment, at the bottom of an aquatic ecosystem. It can be used to describe the organisms that live on, or in, the bottom of a waterbody. (1)

**Benthic organisms.** Organisms living in, or on, bottom substrates in aquatic ecosystems.(1)

**Best management practices (BMPs).** Methods, measures, or practices determined to be reasonable and cost-effective means for a landowner to meet certain, generally nonpoint source, pollution control needs. BMPs include structural and nonstructural controls and operation and maintenance procedures. (1).

**Bioassessment.** Evaluation of the condition of an ecosystem that uses biological surveys and other direct measurements of the resident biota. (2)

**Biometric**. (Biological Metric) The study of biological phenomena by measurements and statistics.

**Box and whisker plot.** A graphical representation of the mean, lower quartile, upper quartile, upper limit, lower limit, and outliers of a data set.

**Calibration.** The process of adjusting model parameters within physically defensible ranges until the resulting predictions give a best possible good fit to observed data. (1)

**Causal analysis**. A process in which data and other information are organized and evaluated using quantitative and logical techniques to determine the likely cause of an observed condition. (2)

**Causal association.** A correlation or other association between measures or observations of two entities or processes which occurs because of an underlying causal relationship. (2)

**Causal mechanism**. The process by which a cause induces an effect. (2)

**Causal relationship**. The relationship between a cause and its effect. (2)

**Cause.** 1. That which produces an effect (a general definition).

2. A stressor or set of stressors that occur at an intensity, duration and frequency of exposure that results in a change in the ecological condition (a SI-specific definition). (2)

**Channel.** A natural stream that conveys water; a ditch or channel excavated for the flow of water. (1)

**Chloride.** An atom of chlorine in solution; an ion bearing a single negative charge. (1)

**Clean Water Act (CWA).** The Clean Water Act (formerly referred to as the Federal Water Pollution Control Act or Federal Water Pollution Control Act Amendments of 1972), Public Law 92-500, as amended by Public Law 96-483 and Public Law 97-117, 33 U.S.C. 1251 et seq. The Clean Water Act (CWA) contains a number of provisions to restore and maintain the quality of the nation's water resources. One of these provisions is Section 303(d), which establishes the TMDL program. (1)

**Coefficient of determination**. Represents the proportion of the total sample variability around y that is explained by the linear relationship between *y* and *x*. (In simple linear regression, it may also be computed as the square of the coefficient of correlation *r.)* (3)

**Concentration.** Amount of a substance or material in a given unit volume of solution; usually measured in milligrams per liter (mg/L) or parts per million (ppm). (1)

**Concentration-based limit.** A limit based on the relative strength of a pollutant in a waste stream, usually expressed in milligrams per liter (mg/L). (1)

**Concentration-response model**. A quantitative (usually statistical) model of the relationship between the concentration of a chemical to which a population or community of organisms is exposed and the frequency or magnitude of a biological response. (2)

**Confluence.** The point at which a river and its tributary flow together.

**Contamination.** The act of polluting or making impure; any indication of chemical, sediment, or biological impurities. (1)

**Continuous discharge.** A discharge that occurs without interruption throughout the operating hours of a facility, except for infrequent shutdowns for maintenance, process changes, or other similar activities. (1)

**Conventional pollutants.** As specified under the Clean Water Act, conventional contaminants include suspended solids, coliform bacteria, high biochemical oxygen demand, pH, and oil and grease. (1)

**Conveyance.** A measure of the of the water carrying capacity of a channel section. It is directly proportional to the discharge in the channel section.

**Cost-share program.** A program that allocates project funds to pay a percentage of the cost of constructing or implementing a best management practice. The remainder of the costs are paid by the producer (s). (1)

**Cross-sectional area.** Wet area of a waterbody normal to the longitudinal component of the flow. (1)

**Critical condition.** The critical condition can be thought of as the "worst case" scenario of environmental conditions in the waterbody in which the loading expressed in the TMDL for the pollutant of concern will continue to meet water quality standards. Critical conditions are the combination of environmental factors (e.g., flow, temperature, etc.) that results in attaining and maintaining the water quality criterion and has an acceptably low frequency of occurrence. (1)

**Decay.** The gradual decrease in the amount of a given substance in a given system due to various sink processes including chemical and biological transformation, dissipation to other environmental media, or deposition into storage areas. (1)

**Decomposition.** Metabolic breakdown of organic materials; the formation of by-products of decomposition releases energy and simple organic and inorganic compounds. (1)

**Designated uses.** Those uses specified in water quality standards for each waterbody or segment whether or not they are being attained. (1)

**Deterministic model.** A model that does not include built-in variability: same input will always result in the same output. (1)

**Dilution.** The addition of some quantity of less-concentrated liquid (water) that results in a decrease in the original concentration. (1)

**Direct runoff.** Water that flows over the ground surface or through the ground directly into streams, rivers, and lakes. (1)

**Discharge.** Flow of surface water in a stream or canal, or the outflow of groundwater from a flowing artesian well, ditch, or spring. Can also apply to discharge of liquid effluent from a facility or to chemical emissions into the air through designated venting mechanisms. (1)

**Discharge Monitoring Report (DMR).** Report of effluent characteristics submitted by a municipal or industrial facility that has been granted an NPDES discharge permit. (1)

**Discharge permits (under NPDES).** A permit issued by the U.S. EPA or a state regulatory agency that sets specific limits on the type and amount of pollutants that a municipality or industry can discharge to a receiving water; it also includes a compliance schedule for achieving those limits. The permit process was established under the National Pollutant Discharge Elimination System, under provisions of the Federal Clean Water Act. (1)

**Dispersion.** The spreading of chemical or biological constituents, including pollutants, in various directions at varying velocities depending on the differential in-stream flow characteristics. (1)

**Diurnal.** Actions or processes that have a period or a cycle of approximately one tidal-day or are completed within a 24-hour period and that recur every 24 hours. Also, the occurrence of an activity/process during the day rather than the night. (1)

**DNA.** Deoxyribonucleic acid. The genetic material of cells and some viruses.

**Drainage basin.** A part of a land area enclosed by a topographic divide from which direct surface runoff from precipitation normally drains by gravity into a receiving water. Also referred to as a watershed, river basin, or hydrologic unit. (1)

**Dynamic model.** A mathematical formulation describing and simulating the physical behavior of a system or a process and its temporal variability. (1)

**Dynamic simulation.** Modeling of the behavior of physical, chemical, and/or biological phenomena and their variations over time. (1)

**Ecosystem.** An interactive system that includes the organisms of a natural community association together with their abiotic physical, chemical, and geochemical environment. (1)

**Effluent.** Municipal sewage or industrial liquid waste (untreated, partially treated, or completely treated) that flows out of a treatment plant, septic system, pipe, etc. (1)

**Effluent guidelines.** The national effluent guidelines and standards specify the achievable effluent pollutant reduction that is attainable based upon the performance of treatment technologies employed within an industrial category. The National Effluent Guidelines Program was established with a phased approach whereby industry would first be required to meet interim limitations based on best practicable control technology currently available for existing sources (BPT). The second level of effluent limitations to be attained by industry was referred to as best available technology economically achievable (BAT), which was established primarily for the control of toxic pollutants. (1)

**Effluent limitation.** Restrictions established by a state or EPA on quantities, rates, and concentrations in pollutant discharges. (1)

**Empirical model.** Use of statistical techniques to discern patterns or relationships underlying observed or measured data for large sample sets. Does not account for physical dynamics of waterbodies. (1)

**Endpoint.** An endpoint (or indicator/target) is a characteristic of an ecosystem that may be affected by exposure to a stressor. Assessment endpoints and measurement endpoints are two distinct types of endpoints commonly used by resource managers. An assessment endpoint is the formal expression of a valued environmental characteristic and should have societal relevance (an indicator). A measurement endpoint is the expression of an observed or measured response to a stress or disturbance. It is a measurable environmental characteristic that is related to the valued environmental characteristic chosen as the assessment endpoint. The numeric criteria that are part of traditional water quality standards are good examples of measurement endpoints (targets). (1)

**Enhancement.** In the context of restoration ecology, any improvement of a structural or functional attribute. (1)

**Evapotranspiration.** The combined effects of evaporation and transpiration on the water balance. Evaporation is water loss into the atmosphere from soil and water surfaces. Transpiration is water loss into the atmosphere as part of the life cycle of plants.

**Existing use.** Use actually attained in the waterbody on or after November 28, 1975, whether or not it is included in the water quality standards (40 CFR 131.3). (1)

**Fate of pollutants.** Physical, chemical, and biological transformation in the nature and changes of the amount of a pollutant in an environmental system. Transformation processes are pollutant-specific. Because they have comparable kinetics, different formulations for each pollutant are not required. (1)

**First-order kinetics.** The type of relationship describing a dynamic reaction in which the rate of transformation of a pollutant is proportional to the amount of that pollutant in the environmental system. (1)

**Flux.** Movement and transport of mass of any water quality constituent over a given period of time. Units of mass flux are mass per unit time. (1)

**General Standard.** A narrative standard that ensures the general health of state waters. All state waters, including wetlands, shall be free from substances attributable to sewage, industrial waste, or other waste in concentrations, amounts, or combinations which contravene established standards or interfere directly or indirectly with designated uses of such water or which are inimical or harmful to human, animal, plant, or aquatic life (9VAC25-260-20). (4)

**Geometric mean.** A measure of the central tendency of a data set that minimizes the effects of extreme values.

**GIS.** Geographic Information System. A system of hardware, software, data, people, organizations and institutional arrangements for collecting, storing, analyzing and disseminating information about areas of the earth. (Dueker and Kjerne, 1989)

**Gob Pile.** The term applied to that part of the mine from which the coal has been removed and the space more or less filled up with waste. Also, the loose waste in a mine. Also called goaf.

**Ground water.** The supply of fresh water found beneath the earths surface, usually in aquifers, which supply wells and springs. Because ground water is a major source of drinking water, there is growing concern over contamination from leaching agricultural or industrial pollutants and leaking underground storage tanks. (1)

**HSPF.** Hydrological Simulation Program – Fortran. A computer simulation tool used to mathematically model nonpoint source pollution sources and movement of pollutants in a watershed.

**Hydrograph.** A graph showing variation of stage (depth) or discharge in a stream over a period of time. (1)

**Hydrologic cycle.** The circuit of water movement from the atmosphere to the earth and its return to the atmosphere through various stages or processes, such as precipitation, interception, runoff, infiltration, storage, evaporation, and transpiration. (1)

**Hydrology.** The study of the distribution, properties, and effects of water on the earth's surface, in the soil and underlying rocks, and in the atmosphere. (1)

**Hyetograph.** Graph of rainfall rate versus time during a storm event. (1)

**Impairment.** A detrimental effect on the biological integrity of a water body that prevents attainment of the designated use. (2)

**IMPLND.** An impervious land segment in HSPF. It is used to model land covered by impervious materials, such as pavement.

**Indicator.** A measurable quantity that can be used to evaluate the relationship between pollutant sources and their impact on water quality. (1)

**Indicator organism.** An organism used to indicate the potential presence of other (usually pathogenic) organisms. Indicator organisms are usually associated with the other organisms, but are usually more easily sampled and measured. (1)

**Indirect causation**. The induction of effects through a series of cause-effect relationships, so that the impaired resource may not even be exposed to the initial cause. (2)

**Indirect effects.** Changes in a resource that are due to a series of cause-effect relationships rather than to direct exposure to a contaminant or other stressor. (2)

**Infiltration capacity.** The capacity of a soil to allow water to infiltrate into or through it during a storm. (1)

**In situ.** In place; in situ measurements consist of measurements of components or processes in a full-scale system or a field, rather than in a laboratory. (1)

**Interflow.** Runoff which travels just below the surface of the soil.

**Isolate.** An inbreeding biological population that is isolated from similar populations by physical or other means.

**Leachate.** Water that collects contaminants as it percolates through contaminated soil, mine wastes, and landfills. Leaching can result in hazardous substances being delivered to surface water, ground water, or soil.

**Limits (upper and lower).** The lower limit equals the lower quartile – 1.5x(upper quartile – lower quartile), and the upper limit equals the upper quartile + 1.5x(upper quartile – lower quartile). Values outside these limits are referred to as outliers.

**Loading, Load, Loading rate.** The total amount of material (pollutants) entering the system from one or multiple sources; measured as a rate in weight per unit time. (1)

**Load allocation (LA).** The portion of a receiving waters loading capacity attributed either to one of its existing or future nonpoint sources of pollution or to natural background sources. Load allocations are best estimates of the loading, which can range from reasonably accurate estimates to gross allotments, depending on the availability of data and appropriate techniques for predicting the loading. Wherever possible, natural and nonpoint source loads should be distinguished. (40 CFR 130.2(g)) (1)

**Loading capacity (LC).** The greatest amount of loading a waterbody can receive without violating water quality standards. (1)

**Margin of safety (MOS).** A required component of the TMDL that accounts for the uncertainty about the relationship between the pollutant loads and the quality of the receiving waterbody (CWA Section 303(d)(1)(C)). The MOS is normally incorporated into the conservative assumptions used to develop TMDLs (generally within the calculations or models) and approved by EPA either individually or in state/EPA agreements. If the MOS needs to be larger than that which is allowed through the conservative assumptions, additional MOS can be added as a separate component of the TMDL (in this case, quantitatively, a TMDL = LC = WLA + LA + MOS). (1)

**Mass balance.** An equation that accounts for the flux of mass going into a defined area and the flux of mass leaving the defined area. The flux in must equal the flux out. (1)

**Mass loading.** The quantity of a pollutant transported to a waterbody. (1)

**Mathematical model.** A system of mathematical expressions that describe the spatial and temporal distribution of water quality constituents resulting from fluid transport and the one or more individual processes and interactions within some prototype aquatic ecosystem. A mathematical water quality model is used as the basis for waste load allocation evaluations. (1)

**Mean.** The sum of the values in a data set divided by the number of values in the data set.

**MGD.** Million gallons per day. A unit of water flow, whether discharge or withdraw.

**Mine Tailings**. Discarded low-grade ore or waste materials that are found accumulated into piles, next to or downhill from tunnel or up shaft openings; mine dumps or waste debris.

**Mine Spoils**. Earth and rock overburden which is excavated during mining operations.

**Mitigation.** Actions taken to avoid, reduce, or compensate for the effects of environmental damage. Among the broad spectrum of possible actions are those which restore, enhance, create, or replace damaged ecosystems. (1)

**Monitoring.** Periodic or continuous surveillance or testing to determine the level of compliance with statutory requirements and/or pollutant levels in various media or in humans, plants, and animals. (1)

**Mood's median test.** A nonparametric (distribution-free) test used to test the equality of medians from two or more populations. (MINITAB, 1995)

**Multivariate Regression**. A functional relationship between 1 dependent variable and multiple independent variables that are often empirically determined from data and are used especially to predict values of one variable when given values of the others.

**Narrative criteria.** Nonquantitative guidelines that describe the desired water quality goals. (1)

**National Pollutant Discharge Elimination System (NPDES).** The national program for issuing, modifying, revoking and reissuing, terminating, monitoring, and enforcing permits, and imposing and enforcing pretreatment requirements, under Sections 307, 402, 318, and 405 of the Clean Water Act. (1)

**Natural waters.** Flowing water within a physical system that has developed without human intervention, in which natural processes continue to take place. (1)

**Nonpoint source.** Pollution that originates from multiple sources over a relatively large area. Nonpoint sources are diffuse, hydrologically driven pollution sources. They can be divided into source activities related to either land or water use including mining practices, forest practices, and urban and rural runoff.

**Numeric targets.** A measurable value determined for the pollutant of concern which, if achieved, is expected to result in the attainment of water quality standards in the listed waterbody. (1)

**Numerical model.** Model that approximates a solution of governing partial differential equations which describe a natural process. The approximation uses a numerical discretization of the space and time components of the system or process. (1)

**Organic matter.** The organic fraction that includes plant and animal residue at various stages of decomposition, cells and tissues of soil organisms, and substances synthesized by the soil population. Commonly determined as the amount of organic material contained in a soil or water sample. (1)

**Parameter**. A numerical descriptive measure of a population. Since it is based on the observations of the population, its value is almost always unknown.

**Peak runoff.** The highest value of the stage or discharge attained by a flood or storm event; also referred to as flood peak or peak discharge. (1)

**PERLND.** A pervious land segment in HSPF. It is used to model a particular land use segment within a subwatershed (e.g. pasture, urban land, or crop land).

**Permit.** An authorization, license, or equivalent control document issued by EPA or an approved federal, state, or local agency to implement the requirements of an environmental regulation; e.g., a permit to operate a wastewater treatment plant or to operate a facility that may generate harmful emissions. (1)

**Permit Compliance System (PCS).** Computerized management information system that contains data on NPDES permit-holding facilities. PCS keeps extensive records on more than 65,000 active water-discharge permits on sites located throughout the nation. PCS tracks permit, compliance, and enforcement status of NPDES facilities. (1)

**Phased/Staged approach.** Under the staged approach to TMDL development, load allocations and wasteload allocations are calculated using the best available data and information recognizing the need for additional monitoring data to accurately characterize sources and loadings. The staged approach is typically employed when nonpoint sources dominate. It provides for the implementation of load reduction strategies while collecting additional data. (1)

**Point source.** Any conveyance such as a ditch, tunnel, conduit, or pipe from which pollutants are discharged. Point sources have a single point of entry with a direct path to a waterbody. Point sources can also include pollutant loads contributed by tributaries to the main receiving water stream or river. (1)

**Pollutant.** Dredged spoil, solid waste, incinerator residue, sewage, garbage, sewage sludge, munitions, chemical wastes, biological materials, radioactive materials, heat, wrecked or discarded equipment, rock, sand, cellar dirt, and industrial, municipal, and agricultural waste discharged into water. (CWA Section 502(6)). (1)

**Pollution.** Generally, the presence of matter or energy whose nature, location, or quantity produces undesired environmental effects. Under the Clean Water Act, for example, the term is defined as the man-made or man-induced alteration of the physical, biological, chemical, and radiological integrity of water. (1)

**Postaudit.** A subsequent examination and verification of a model's predictive performance following implementation of an environmental control program. (1)

**Privately owned treatment works.** Any device or system that is (a) used to treat wastes from any facility whose operator is not the operator of the treatment works and (b) not a publicly owned treatment works. (1)

**Public comment period.** The time allowed for the public to express its views and concerns regarding action by EPA or states (e.g., a *Federal Register* notice of a proposed rule-making, a public notice of a draft permit, or a Notice of Intent to Deny). (1)

**Publicly owned treatment works (POTW).** Any device or system used in the treatment (including recycling and reclamation) of municipal sewage or industrial wastes of a liquid nature that is owned by a state or municipality. This definition includes sewers, pipes, or other conveyances only if they convey wastewater to a POTW providing treatment. (1)

**Quartile.** The $25^{th}$, $50^{th}$, and $75^{th}$ percentiles of a data set. A percentile (p) of a data set ordered by magnitude is the value that has at most p% of the measurements in the data set below it, and (100-p)% above it. The $50^{th}$ quartile is also known as the median. The $25^{th}$ and $75^{th}$ quartiles are referred to as the lower and upper quartiles, respectively.

**Receiving waters.** Creeks, streams, rivers, lakes, estuaries, ground-water formations, or other bodies of water into which surface water and/or treated or untreated waste are discharged, either naturally or in man-made systems. (1)

**Re-mining**. Extracting resources from land previously mined. This method is often used to reclaim abandoned mine areas.

**Reserve capacity.** Pollutant loading rate set aside in determining stream waste load allocation, accounting for uncertainty and future growth. (1)

**Residence time.** Length of time that a pollutant remains within a section of a stream or river. The residence time is determined by the streamflow and the volume of the river reach or the average stream velocity and the length of the river reach. (1)

**Restoration.** Return of an ecosystem to a close approximation of its presumed condition prior to disturbance. (1)

**Riparian areas.** Areas bordering streams, lakes, rivers, and other watercourses. These areas have high water tables and support plants that require saturated soils during all or part of the year. Riparian areas include both wetland and upland zones. (1)

**Riparian zone.** The border or banks of a stream. Although this term is sometimes used interchangeably with floodplain, the riparian zone is generally regarded as relatively narrow compared to a floodplain. The duration of flooding is generally much shorter, and the timing less predictable, in a riparian zone than in a river floodplain. (1)

**Roughness coefficient.** A factor in velocity and discharge formulas representing the effects of channel roughness on energy losses in flowing water. Manning's "n" is a commonly used roughness coefficient. (1)

**Runoff.** That part of precipitation, snowmelt, or irrigation water that runs off the land into streams or other surface water. It can carry pollutants from the air and land into receiving waters. (1)

**Seasonal Kendall test.** A statistical tool used to test for trends in data, which is unaffected by seasonal cycles. (Gilbert, 1987)

**Sewer.** A channel or conduit that carries wastewater and storm water runoff from the source to a treatment plant or receiving stream. Sanitary sewers carry household, industrial, and commercial waste. Storm sewers carry runoff from rain or snow. Combined sewers handle both. (1)

**Simulation.** The use of mathematical models to approximate the observed behavior of a natural water system in response to a specific known set of input and forcing conditions. Models that have been validated, or verified, are then used to predict the response of a natural water system to changes in the input or forcing conditions. (1)

**Slope.** The degree of inclination to the horizontal. Usually expressed as a ratio, such as 1:25 or 1 on 25, indicating one unit vertical rise in 25 units of horizontal distance, or in a decimal fraction (0.04), degrees (2 degrees 18 minutes), or percent (4 percent). (1)

**Source.** An origination point, area, or entity that releases or emits a stressor. A source can alter the normal intensity, frequency, or duration of a natural attribute, whereby the attribute then becomes a stressor. (2)

**Spatial segmentation.** A numerical discretization of the spatial component of a system into one or more dimensions; forms the basis for application of numerical simulation models. (1)

**Stakeholder.** Any person with a vested interest in the TMDL development.

**Standard deviation.** A measure of the variability of a data set. The positive square root of the variance of a set of measurements.

**Standard error.** The standard deviation of a distribution of a sample statistic, esp. when the mean is used as the statistic.

**Statistical significance.** An indication that the differences being observed are not due to random error. The p-value indicates the probability that the differences are due to random error (i.e. a low p-value indicates statistical significance).

**Steady-state model.** Mathematical model of fate and transport that uses constant values of input variables to predict constant values of receiving water quality concentrations. Model variables are treated as not changing with respect to time. (1)

**Stepwise regression**. All possible one-variable models of the form $E(y) = B_0 + B_1 x_1$ are fit and the "best" $x_1$ is selected based on the *t*-test for $B_1$. Next, two-variable models of the form $E(y) = B_0 + B_1 x_1 + B_2 x_i$ are fit (where $x_i$ is the variable selected in the first step): the "second best" $x_i$ is selected based on the test for $B_2$. The process continues in this fashion until no more "important" $x$'s can be added to the model. (3)

**Storm runoff.** Storm water runoff, snowmelt runoff, and surface runoff and drainage; rainfall that does not evaporate or infiltrate the ground because of impervious land surfaces or a soil infiltration rate lower than rainfall intensity, but instead flows onto adjacent land or into waterbodies or is routed into a drain or sewer system. (1)

**Streamflow.** Discharge that occurs in a natural channel. Although the term "discharge" can be applied to the flow of a canal, the word "streamflow" uniquely describes the discharge in a surface stream course. The term "streamflow" is more general than "runoff" since streamflow may be applied to discharge whether or not it is affected by diversion or regulation. (1)

**Stream Reach**. A straight portion of a stream.

**Stream restoration.** Various techniques used to replicate the hydrological, morphological, and ecological features that have been lost in a stream because of urbanization, farming, or other disturbance. (1)

**Stressor.** Any physical, chemical, or biological entity that can induce an adverse response. (2)

**Surface area.** The area of the surface of a waterbody; best measured by planimetry or the use of a geographic information system. (1)

**Surface runoff.** Precipitation, snowmelt, or irrigation water in excess of what can infiltrate the soil surface and be stored in small surface depressions; a major transporter of nonpoint source pollutants. (1)

**Surface water.** All water naturally open to the atmosphere (rivers, lakes, reservoirs, ponds, streams, impoundments, seas, estuaries, etc.) and all springs, wells, or other collectors directly influenced by surface water. (1)

**Technology-based standards.** Effluent limitations applicable to direct and indirect sources that are developed on a category-by-category basis using statutory factors, not including water quality effects. (1)

**Timestep.** An increment of time in modeling terms. The smallest unit of time used in a mathematical simulation model (e.g. 15-minutes, 1-hour, 1-day).

**Topography.** The physical features of a geographic surface area including relative elevations and the positions of natural and man-made features. (1)

**Total Maximum Daily Load (TMDL).** The sum of the individual wasteload allocations (WLAs) for point sources, load allocations (LAs) for nonpoint sources and natural background, plus a margin of safety (MOS). TMDLs can be expressed in terms of mass per time, toxicity, or other appropriate measures that relate to a state's water quality standard. (1)

**Transport of pollutants (in water).** Transport of pollutants in water involves two main processes: (1) advection, resulting from the flow of water, and (2) dispersion, or transport due to turbulence in the water. (1)

**Tributary.** A lower order-stream compared to a receiving waterbody. "Tributary to" indicates the largest stream into which the reported stream or tributary flows. (1)

**Validation (of a model).** Process of determining how well the mathematical model's computer representation describes the actual behavior of the physical processes under investigation. A validated model will have also been tested to ascertain whether it accurately and correctly solves the equations being used to define the system simulation. (1)

**Variance.** A measure of the variability of a data set. The sum of the squared deviations (observation – mean) divided by (number of observations) – 1.

**VADACS.** Virginia Department of Agriculture and Consumer Services.

**VADCR.** Virginia Department of Conservation and Recreation.

**VADEQ.** Virginia Department of Environmental Quality.

**VADMLR.** Virginia Department of Mine Land Reclamation.

**VADMME.** Virginia Department of Mines, Minerals, and Energy.

**VDH.** Virginia Department of Health.

**Wasteload allocation (WLA).** The portion of a receiving waters' loading capacity that is allocated to one of its existing or future point sources of pollution. WLAs constitute a type of water quality-based effluent limitation (40 CFR 130.2(h)). (1)

**Wastewater.** Usually refers to effluent from a sewage treatment plant. See also **Domestic wastewater**. (1)

**Wastewater treatment.** Chemical, biological, and mechanical procedures applied to an industrial or municipal discharge or to any other sources of contaminated water to remove, reduce, or neutralize contaminants. (1)

**Water quality.** The biological, chemical, and physical conditions of a waterbody. It is a measure of a waterbody's ability to support beneficial uses. (1)

**Water quality-based effluent limitations (WQBEL).** Effluent limitations applied to dischargers when technology-based limitations alone would cause violations of water quality standards. Usually WQBELs are applied to discharges into small streams. (1)

**Water quality-based permit.** A permit with an effluent limit more stringent than one based on technology performance. Such limits might be necessary to protect the designated use of receiving waters (e.g., recreation, irrigation, industry, or water supply). (1)

**Water quality criteria.** Levels of water quality expected to render a body of water suitable for its designated use, composed of numeric and narrative criteria. Numeric criteria are scientifically derived ambient concentrations developed by EPA or states for various pollutants of concern to protect human health and aquatic life. Narrative criteria are statements that describe the desired water quality goal. Criteria are based on specific levels of pollutants that would make the water harmful if used for drinking, swimming, farming, fish production, or industrial processes. (1)

**Water quality standard.** Law or regulation that consists of the beneficial designated use or uses of a waterbody, the numeric and narrative water quality criteria that are necessary to protect the use or uses of that particular waterbody, and an antidegradation statement. (1)

**Watershed.** A drainage area or basin in which all land and water areas drain or flow toward a central collector such as a stream, river, or lake at a lower elevation. (1)

**WQIA.** Water Quality Improvement Act.

(1) USEPA (1999).
(2) USEPA (2000).
(3) McClave, James T., et al. (1998).
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